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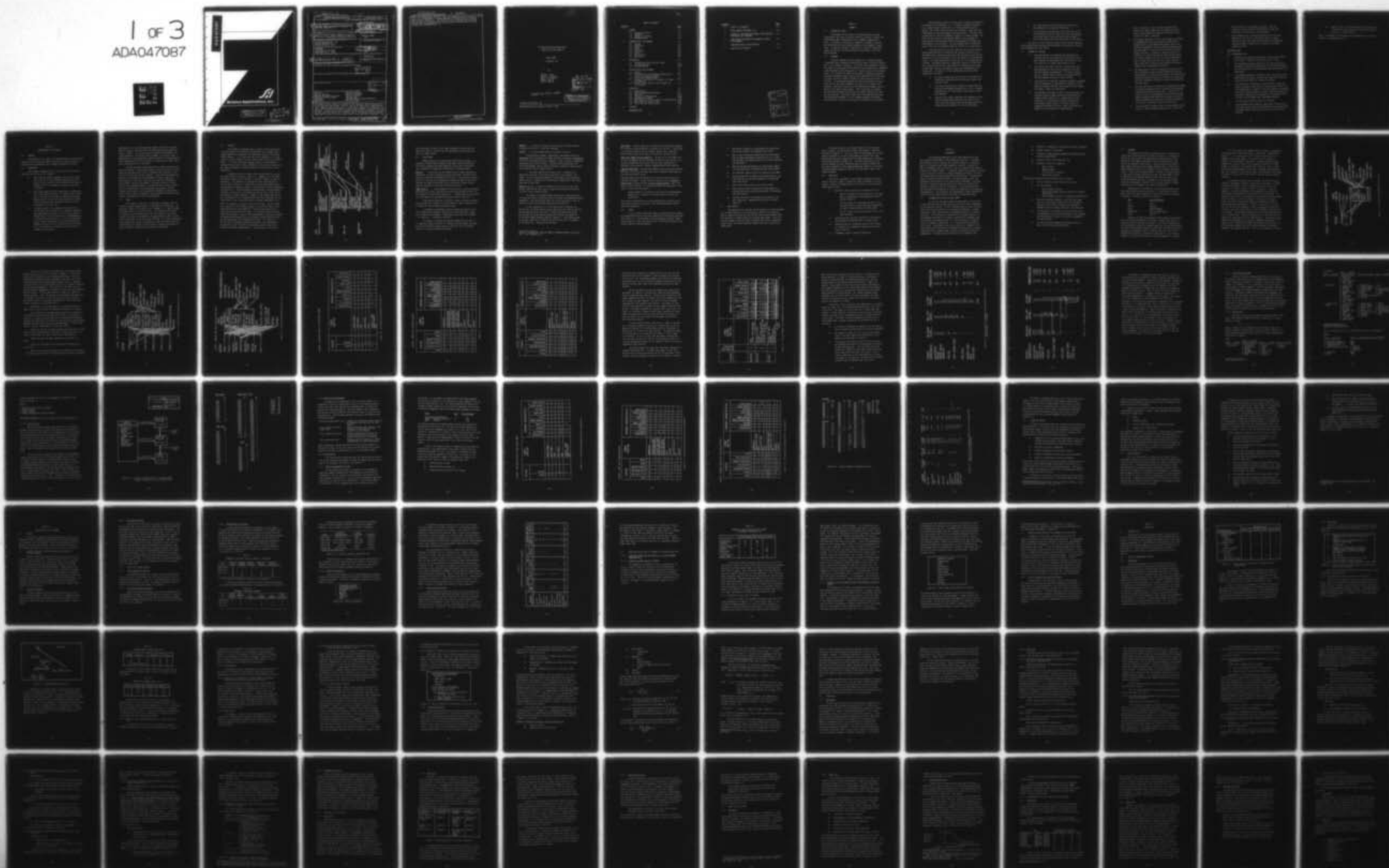

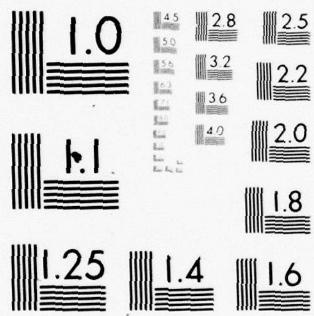

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The purpose of this study is to determine what has been learned about the value of tactical mobility and what it means, and to delineate those investigations still needed to measure this value. It focuses on tactical, as opposed to strategic, mobility and concentrates on ground combat elements in the theater of operations. It does not include an exploration of mobility technology. The basic approach involved conduct of a literature search to determine what information regarding the value of tactical mobility was in the available literature. This

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VALUE OF TACTICAL MOBILITY

FINAL REPORT

4 November 1977

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Section 1

SUMMARY

1.1 PURPOSE AND SCOPE

The purpose of this study is to determine what has been learned about the value of tactical mobility and what it means, and to delineate those investigations still needed to measure this value. It focuses on tactical, as opposed to strategic, mobility and concentrates on ground combat elements in the theater of operations. It does not include an exploration of mobility technology except to constrain the effort to mobility achievable in the 1977-2000 timeframe.

1.2 APPROACH

The basic approach involved conduct of a literature search to determine what information regarding the value of tactical mobility was in the available literature. This effort was augmented by convening, under the sponsorship and direction of the study sponsor (DUSA(OR)), a working meeting of leading experts in tactical mobility and related areas. This provided an update to the body of literature by making available information about current and planned mobility efforts and also made available valuable insights by those doing active work in the area. It soon became apparent that the classification and evaluation of the available information, as well as its analysis and synthesis, required a structure of the relationship between tactical mobility and combat effectiveness. Such a structure or taxonomy was developed and specifies missions and combat functions for each of three echelons: One-on-One, Small Unit, and Combined Arms Force. The relationship between a list of standard movement performance characteristics, functions and missions was defined at each echelon.

The taxonomy was used to classify every reference according to the elements of the taxonomy, i.e., by echelon, movement characteristic, combat function and mission. If these elements were all present, one or more links was potentially present. These were then investigated to see how thoroughly each was covered. The actual sorting was done on a desk top computer by means of a coding scheme. The result of this analysis indicated the depth of the coverage for every possible link and these results were weighted to reflect the thoroughness of the coverage. This was compared with the potential value of the links to determine gaps and priority for future action.

The other major input to the study was the Tactical Mobility Working Meeting held at the National War College, 26-28 July 1977. The meeting was structured around three working groups which focused separately on One-on-One combat, small unit combat, and combined arms forces. The issues addressed by each group for its assigned echelon included: performance measures, trade-offs, measures of effectiveness, quantification means, quantification analyses already accomplished, data, testing, and analysis gaps, and recommendations for future work. The results of their deliberations may be briefly summarized as follows:

- All groups recognized that the bulk of the effort and literature concerned mobility technology rather than tactical value.
- All groups indicated that trade-offs between mobility and other performance characteristics, e.g., firepower, survivability, C^3, intelligence, human factors, need more emphasis.
- The small unit group recognized the inadequacy of measures of effectiveness that have been used at that level which have concentrated on exchange ratios while ignoring other dimensions of mission performance.

- The large volume of existing test data that has not been adequately analyzed was highlighted.
- A serious gap was recognized in that there are no predictive models which can relate the total time required for moving large military forces to vehicle speed or any of the other factors that contribute to such delays.

The results of the literature search and the Tactical Mobility Working Meeting were analyzed and synthesized to produce the findings and recommendations that follow.

1.3 SUMMARY OF FINDINGS

- The contributions of technology and engineering to tactical mobility have been and are continuing to be well examined and documented; the contribution of tactical mobility to combat effectiveness is not.
- For the past few years, mobility investigations have been dominated by one-on-one survivability and hardware performance considerations. The thrust of both the U.S. Armored Combat Vehicle Test Program (ACVTP) and FRG programs continues in this direction.
- Investigations of combined firepower and mobility systems tend to concentrate on the effects of changes in firepower performance with much less emphasis on the effects of changes in mobility performance.
- The Army does not appear to have a structural basis for trade-off analysis among factors which contribute to combat mission success, e.g., between mobility and firepower, C^3, intelligence, support and many more. Among these, human factors, to include control of maneuvering vehicles and units, seem to have been submerged in the survivability investigations.

- There is conflict in the literature regarding the trade-off of armor protection for movement characteristics; some analyses are showing an increase in survivability, others a decrease.

- The taxonomy developed in this study appears to provide an adequate basis for structuring the relationship between mobility and combat effectiveness and for assessing the potential value of trade-offs between movement characteristics at the various echelons and even between echelons. A program to expand the mobility taxonomy to include other factors contributing to mission success appears fruitful in terms of discovering gaps in areas other than mobility, correlating the Army's data base, structuring the testing and analysis programs, and investigating trade-offs.

- The application of such an expanded classification system, structured in terms of Army ground force mission accomplishment, to the testing data base and other source data bases would be fruitful as a means for correlating existing information and help to close tactical mobility and other gaps.

- The tactical mobility literature has neglected the impact of movement characteristics on tactical mission accomplishment above the one-on-one level. Much of this relates to a lack of understanding of the notion of block speed and the current inability to relate all tactical vehicle movement characteristics to combat outcomes at all echelons, especially above one-on-one level.

- The truism that increased range is substitutable for mobility in certain support functions (e.g., artillery,

ground radar) must be carefully examined. The non-linearity of this trade-off relationship may make this assertion valid only over a limited domain.

- The fundamental gap in quantifying the value of tactical mobility is the lack of a predictive model for determining the total time (from causative event to completion) required to move a combat force in order to carry out a military mission.

1.4 RECOMMENDATIONS

It is recommended that:

- The mobility taxonomy be expanded to include other factors that impact on combat mission outcome at all levels.
- The expanded taxonomy be applied to the testing data base and other original source data bases (to include field tests and unit exercises) to correlate data and close mobility and other gaps.
- The expanded taxonomy be applied to guide resolution of the mobility/agility versus survivability issue and to discover other areas for beneficial trade-off research.
- Existing models be improved to sensitize their combat outcomes to movement characteristics impacting on tactical mission performance in addition to relative resource consumption. This effort should encompass a wider range of scenarios than heretofore addressed and be conducted in consonance with or as a part of the TRADOC model improvement program.
- A "block speed" modeling effort be initiated.
- The Army/DARPA ACVTP program be continually reviewed to ensure that tactical mobility considerations are not dominated by hardware technology and pure one-on-one survivability testing.

- Design of small unit free maneuver testing program be initiated with the objective of examining one-on-one results in a broader context.

Note: The sequence for executing these recommendations is shown in the chart in paragraph 5.8.4.6.

Section 2

ELABORATION OF THE PROBLEM

2.1 PURPOSE

The purpose of this study is to determine what has been learned about the value of tactical mobility and what it means, and to delineate those investigations still needed to measure this value.

2.2 BACKGROUND

Every combat commander has an intuitive but firm conviction that mobility has value. For example:

- Every fighting vehicle commander knows that the speed with which he can bound between covered positions is one key to his survival on the battlefield and that the reaction time of his armament, relative to the enemy is another.

- Every tank platoon/infantry squad leader is aware that for a given piece of terrain, his average rate of movement in the face of the enemy is constrained by enemy weapon reaction time and his own maximum cross-country velocity; he also knows that enemy reaction time can be degraded by his own fires.

- At higher echelons, the commander realizes that his tactical mobility, as much as his firepower, determines the combat power he can mass at the critical juncture, whether that be the final assault or a disengagement in a successful delaying action. He is also increasingly aware of other interactions such as the relationship between the mobility of his fighting vehicles and that of his fire support, air defense, service support and command control systems.

Nevertheless, he is hard pressed when asked to justify his requirement for tactical mobility with a rationale more sophisticated than "more is better". In the real world of competing requirements for scarce resources, such quantification demands, at the very least, a determination of the operational payoff achieved by increased mobility and a determination of how this payoff is constrained by other operational characteristics of the force.

The Army has spent considerable sums of money acquiring high mobility vehicles. Increasingly, however, questions are being raised about the expected return on this investment, most recently in connection with the XM-1 and MICV programs. These have highlighted the need for an assessment of the improvement in combat capability, i.e., effectiveness of the force, resulting from mobility improvements. Many agencies, foreign and domestic, have been working on various parts of this complex problem. These efforts have involved a multiplicity of specialties--including operations research, tactics, testing, human factors, and experimental prototyping, among others. There is now a need for integration and assessment of results and for careful consideration of future investigations.

2.3 SCOPE

This study of "tactical" (as opposed to strategic) mobility focuses on ground combat elements in the theater of operations. Of particular concern is the mobility of firepower, i.e., weapon systems like tanks, MICVs, ITVs and artillery. The study does not include an exploration of the technology of mobility except to the extent necessary to restrict consideration to ground mobility that is practically achievable in the time frame 1977-2000. The study concentrates on the operational payoff of increments of mobility rather than cost effectiveness of a specific mobility means, although consideration is given to potential trade-offs that should be considered.

2.4 ECHELONS

Any attempt to integrate what is known, and to discover what is unknown about the relationship between mobility increments and combat payoffs must recognize the hierarchical nature of the ground combat elements. It is clear that the rate of movement of a single vehicle is quite different from the rate at which a division or corps moves. It is also intuitively apparent that the various mobility characteristics (acceleration, gradability, cross country speed, etc.) may impact differently on combat outcomes at various levels in the organization.

A hierarchy which can lead us from tactical mobility to combat effectiveness is shown at Figure 2-1. Fundamental to the whole problem and underlying all the rest is the basic echelon of mobility technology. This echelon is concerned with the transformation of vehicle design criteria, in conjunction with the anticipated natural and man-made environmental factors, into individual vehicle performance characteristics. These performance characteristics include movement, firepower, survivability, and others and are the basic inputs to investigations at higher echelons. However as has already been stated, this investigation is not concerned with mobility technology, per se; the problem is one of relating mobility to combat performance in an effort to determine its value to the military force. We can, therefore, ignore this first echelon except as it provides inputs to the remaining required transformations. The next three echelons are listed below the double line divider. The figure portrays the three identified echelons in terms of the transformations required to convert the movement performance inputs into outputs ending finally with the mission performance of the combined arms force. The figure indicates that the movement performance characteristics developed at the underlying level of mobility technology provide inputs to all three of the higher transformations. Also indicated is the notion

LEVEL	INPUTS	TRANSFORM	OUTPUTS
MOBILITY TECHNOLOGY	VEHICLE DESIGN CRITERIA NATURAL ENVIRONMENT TARGET CRITERIA THREAT CRITERIA ENDURANCE CRITERIA	?	VEHICLE PERF CHARACTERISTICS $\boxed{\text{MOVEMENT}}$ FIREPOWER SURVIVABILITY INTERNAL C^3 (INTERCOM) C^3 (EXTERNAL)
ONE-ON-ONE	FRIENDLY & ENEMY: MOVEMENT PERF FIREPOWER PERF SURVIVABILITY PERF HUMAN FACTORS INTERNAL C^3 (INTERCOM) TRAINING PERF	?	ONE-ON-ONE MISSION PERFORMANCE
SMALL UNIT	FRIENDLY & ENEMY: MOVEMENT PERFORMANCE TOE ONE-ON-ONE MSN PERF C^3 PERFORMANCE HUMAN FACTORS TRAINING PERF PROCEDURES, TACTICS, DOCTRINE	?	SMALL UNIT MISSION PERFORMANCE
COMBINED ARMS FORCE	FRIENDLY & ENEMY: MOVEMENT PERFORMANCE TOE SMALL UNIT MSN PERF C^3 PERFORMANCE HUMAN FACTORS TRAINING PERFORMANCE PROCEDURES, TACTICS, DOCTRINE	?	CA FORCE MISSION PERFORMANCE

Figure 2-1. A Hierarchy for Evaluating Tactical Mobility

that the outputs of each of the lower transforms at One-on-One and small unit level in terms of mission performance provide inputs to the next higher echelon.

2.5 DEFINITIONS

Before going on to discuss other facets of the problem, it is necessary to define what is meant by the words "tactical mobility". This need is perhaps best highlighted by citing some of the definitions uncovered in conducting a preliminary literature search:

<u>MOBILITY</u>: "...the ability of the combat-vehicle system (man/machine combination) to move (relatively) quickly from point to point on the terrain as required to accomplish its mission. Thus relative tactical mobility in vehicles can be measured by comparing means of the times required for them to move from point to point over various terrain types as required by a variety of tactical missions."

<u>COMBAT AGILITY</u>: "...those movements of the vehicle, usually associated with ability to start, stop and turn quickly, which would allow it to avoid enemy fire and terrain obstacles..." (Author goes on to describe its usual measure as acceleration characteristics of vehicle.)

"Tank mobility/agility is defined in terms of those attributes which decrease (or increase) the likelihood of a tank's being hit by a projectile from an attacking weapon system."

Land mobility technology includes technology relative to all land transportation elements including air-cushion vehicles. Areas not included (but contiguous) "technologies associated with weapons, ...air mobility, ...electronic devices..."

"In essence, a vehicle has suitable combat mobility when it is capable of being on-station in a combat area when needed, and when, as part of the total combat system, it can carry out its assigned mission in a timely and effective manner."

MOBILITY: "...ability to traverse a given piece of terrain and the average rate at which it could be traversed."

AGILITY: "...quickly change speed or direction of travel."

Distinguished strategic, operational, battlefield mobility--operational units equipped with combat vehicles to maneuver--battlefield ability of individual vehicle to maneuver in face of actual or potential counteraction by hostile forces. Involves agility--mech basis for rapid displacement from one area to another or weaving to evade hostile fire--reaction time of combat vehicle.

"...The time required for moving a unit in response to a developing situation is more than a function of just nominal road speed. It also involves assessment of intelligence, decision-making, communications, vulnerability to battlefield interdiction, road clearances and closing time."

MOBILIITY (J, A): A quality or capability of military forces which permits them to move from place to place while retaining the ability to fulfill their primary mission.

The reader will probably agree that many of these definitions (or words from which a definition can be inferred) are compartmentalized, symptomatic, and represent the point of view of the author in his approach to a particular problem associated with mobility.

In this connection it is also interesting to consider the definitions of tactical mobility that came out of the Tactical Mobility Working Meeting, 26-28 July 1977.* During that meeting the group was divided into three working groups each of which considered one of the three combat echelons shown at Figure 2-1. Each working group was tasked, inter alia, to define tactical mobility for its echelon of responsibility. These definitions were:

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*REPORT OF PROCEEDINGS, TACTICAL MOBILITY WORKING MEETING, 26-28 July 1977. SAI, 26 August 1977.

ONE-ON-ONE: "Tactical mobility is defined as the controlled movement of a vehicle on the battlefield to achieve its mission." "Controlled" in this sense implies that for whatever reason (e.g., tactical), mobility may or may not be used, or may be only partially used.

SMALL UNIT COMBAT TACTICAL MOBILITY: The ability of the combat unit or its sub-elements to move from point-to-point on the terrain as required to accomplish its mission with the least expenditure of resources (time, materiel, people) commensurate with that mission.

COMBINED ARMS FORCE: "Battalion/brigade/division/corps level tactical mobility is the ability to move and sustain relevant combat power at the place and time of choice."

Although worded quite differently, all three of these definitions share the following: At each echelon they refer to the movement of combat power for some military mission related purpose. Thus, the words tactical mobility will be used throughout the remainder of this report in the following context:

> Tactical mobility is defined as the mission-related movement capability of a vehicle or military force on or near the battlefield.

"On or near the battlefield" can be interpreted as including all of the areas assigned to operational corps and some movements behind corps rear boundaries.

2.6 ISSUES

A list of major issues that need to be addressed with respect to determining the value of tactical mobility can be readily developed from Figure 2-1. The following list was developed from that figure and was used as a basis for tasking each of the working groups at the Tactical Mobility Working Meeting:

- What mobility measures of performance are appropriate for one-on-one/small unit/combined arms force?
- What is the relationship between mobility performance and the other performance characteristics of a single vehicle/small unit/combined arms force? What trade-offs are meaningful?
- What are appropriate measures of effectiveness (MOEs) for one-on-one/small unit/combined arms force combat?
- Do transforms (models) exist for quantifying the MOEs?
- What has been done to measure the effectiveness of tactical mobility at the one-on-one/small unit/combined arms force level?
- What are the data, testing, and analysis gaps?
- What should be done to measure the effectiveness of tactical mobility at the one-on-one/small unit/combined arms force level?
- How does the sum of the foregoing contribute to the basic objective: determining the value of tactical mobility.

2.7 NON-LINEARITY

The perception that average rate of movement of a small maneuver unit is some fraction of the cross-country speed of the individual vehicles comprising that unit and that the relationship between these two velocities is rather complex has already been stated. This relationship between individual vehicle speed and the rate of movement of larger forces, even when unopposed, becomes even more disparate and complicated.

Two analytic models, even though simplistic, provide some useful insights into the nature of these relationships. These are presented at Appendix E. The first examines the movement of a single vehicle by bounds in a hostile environment and develops the ratio between maximum vehicle speed and the average speed actually achieved for minimum exposure to enemy fire. The second examines the relationship between the over-the-ground speed of support elements and the rate of movement of the supported maneuver elements as a function of maximum support range and "set up" and "tear down" times of the support elements.

2.8 OBJECTIVES

The factors considered in the foregoing elaboration of the problem indicate a number of objectives must be reached if the basic purpose, stated at the beginning of this section, is to be realized. These objectives are:

- Establish a basic structure or taxonomy which will:
  - Assist in establishing the relevance of available data to the purpose of quantifying the value of tactical mobility
  - Provide a means for uncovering the gaps in the available data to include data gaps, methodological gaps, trade-off gaps, and testing gaps
  - Assist in prioritizing future effort to fill the gaps uncovered
- Examine the data currently available, to include current programs to determine what is already known
- Determine what the information gaps are with respect to a capability to adequately quantify the value of tactical mobility
- Recommend actions to meet that objective.

Section 3

METHODOLOGY

The methodology employed in this study addresses the four major objectives developed in the preceding discussion. A taxonomy was developed to aid in guiding the literature search, to serve as a basis for classifying pertinent documents, to assist in uncovering gaps in knowledge, and to be used as a tool for assessing the relative priorities of future effort. A literature search was conducted utilizing a basic collection of mobility related documents provided by the Army and other sources including repositories and archives. A second major facet of the data collection effort involved convening, under the sponsorship and direction of the study sponsor (DUSA(OR)), a working meeting of those who have done and/or are doing (to include active planning) significant work on the problem. The collected data were then analyzed and synthesized as a basis for producing the findings and recommendations. The procedures and methodologies (where appropriate) used for each of these phases of the effort are described below.

3.1 TAXONOMY AND CLASSIFICATION SCHEME

An initial literature search was performed to find out how current work and thinking was related to the major issues propounded in the preceding section. As that literature search and our thinking about the size and complexity of the problem progressed, it became increasingly clear that there was a fundamental need for a unifying structure. This structure or taxonomy was an absolute necessity if the movement characteristics normally associated with movement were ever going to be related to what it is that a tactical or fighting force is supposed to accomplish, i.e., to the missions assigned to such forces. The problem, then, was to establish a framework which would portray the relationship of movement characteristics of ground combat vehicles to ground combat missions at appropriate levels of aggregation. The objectives to be met by such a framework were:

- Establish a taxonomy for classifying existing literature
- Develop scope of relationship
- Establish linkages between movement characteristics and mission accomplishment
- Establish a basis for trade-offs, and
- Establish a basis for assessing:
  - What is known
  - Where are gaps
  - Priority for filling gaps
  - What should be done.

The approach to meeting these objectives was as follows:

- Use the echelons already defined at Figure 2-1
- For each echelon:
  - Define combat missions
  - Develop the combat functions required to perform the missions
  - Relate combat functions to movement characteristics
- From this taxonomy, develop a classification scheme which will facilitate evaluation of the coverage afforded by the existing literature with respect to movement-mission linkages, data bases, and trade-offs
- In the absence of hard data as to the relative value and importance of the links established by the taxonomy, use the taxonomy to assist in structuring judgment as to relative value
- Use the structured judgment established above as a basis for prioritizing further effort.

3.1.1 Taxonomy

The echelons that need to be addressed by the taxonomy have already been established and are shown at Figure 2-1. We needed to develop for each echelon the combat missions appropriate for that echelon and the combat functions that had to be exercised by that echelon to accomplish each mission. The next step was to identify those combat functions that encompass movement and to relate these combat movement functions to a standard list of movement characteristics. Since mission accomplishment, in general, requires exercise of more than one combat function and since the same combat function is required for the accomplishment of more than one mission, and since the same multiplicity of linkages is to be expected between functions and movement characteristics, one would expect a diagram portraying these linkages to be a tree-like structure.

Before going on to establish the relationship between movement characteristics and unit mission, it is profitable to take a quick look at the basic properties of any military force, regardless of echelon. A military force at all echelons:

Must	Must Avoid Being
See	Seen
Acquire	Acquired
Move	Denied Movement
Communicate	Denied Communication
Shoot	Shot At

Shown at the left are the basic actions taken by any military force in trying to accomplish its mission. Shown at the right are the threat actions that must be avoided. This line of reasoning can now be extended to examine in greater detail the missions appropriate for each of the echelons previously identified, the specific functions undertaken to accomplish each of those missions, and finally the movement characteristics required for each function. Our principal concern is, of course, the functions for which movement is inherent.

The tree relationship between mission, function, and movement characteristics for the lowest echelon, One-on-One, is depicted at Figure 3-1. This applies only to an individual vehicle once it is engaged in one-on-one combat. Its missions at this stage are simple, but interrelated as indicated: to defeat the enemy weapon (whether this results from killing, rendering incapable of further combat, or causing it to surrender) and to survive. Each is necessary for the accomplishment of the other. Although labeled One-on-One, this figure will also serve to cover the altogether too frequent situation of "one-on-N" for which the mission and functions remain the same.

To accomplish these missions, however, the vehicle must be capable of performing a number of functions as indicated. In order to defeat the target, it must be capable of acquiring it and of tracking it if either target or vehicle are moving. It must be capable of firing at the target and of changing its own position under enemy ground observation to improve its firing position. In order to survive while it is attacking the target, it must be capable of sensing when it is being attacked, it must be able to evade enemy fire, and it must also be capable of changing its position under enemy ground observation. Of these six functions it is only the last two for which movement is both a necessary and sufficient condition, and their relationship to the ten movement characteristics is indicated. The movement characteristics shown have been referred to as a standard set. They are standard only in the sense that the same set has been applied to all three echelons. Ideally they should comprise an orthogonal set of mutually independent parameters. Although the set listed here has been boiled down from an initial list of 29 and does encompass the most important movement performance parameters we recognize that this list is not yet mutually exclusive.

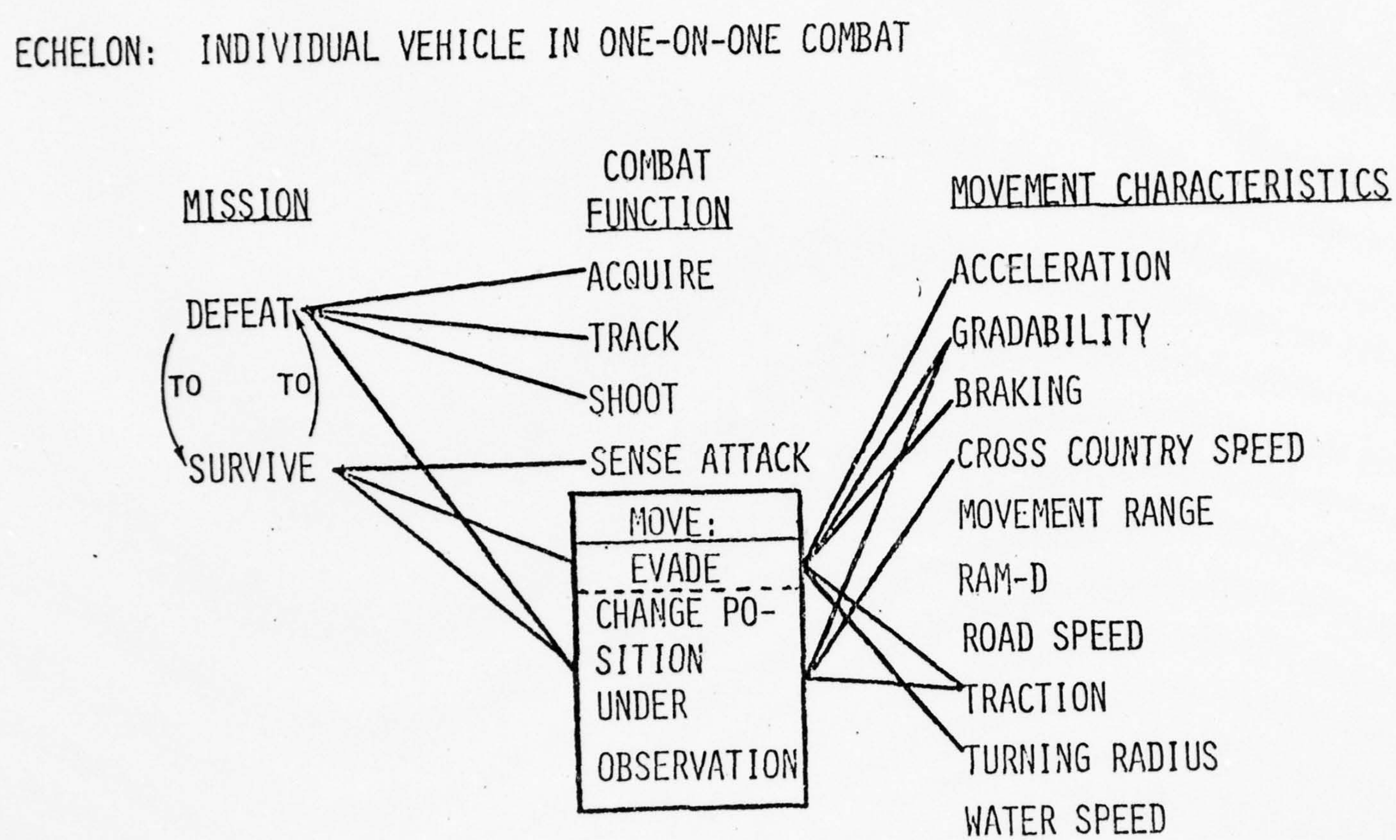

Figure 3-1. Mission/Function/Characteristic Tree 1

Figure 3-2 illustrates the relationship at the next higher echelon, the small unit, i.e., platoon or company. In strict compliance with the hierarchy that has been established, it will be noted that the combat functions performed by the small unit do not include direct attack of enemy targets except as that is subsumed into the function of distributing the fires of its component vehicles into one-on-one engagements. The functions of the small unit are those involved in management of one-on-one actions so as to accomplish the unit mission. Of the eight functions listed, only three encompass movement. Their relationship to the movement characteristics is indicated. Not shown, is the relationship of the "Distribute One-on-One" function to movement characteristics since these were already indicated in the preceding tree.

The reader will note how complex the interrelationship between missions and functions are becoming as we move up in echelon.

This complexity has become almost impossible to represent by this means when we get to the combined arms level as indicated by Figure 3-3. Clearly, the tree depiction is perhaps more satisfying aesthetically than useful as a means for counting the linkages between movement characteristics and mission accomplishment. For the latter purpose, a matrix representation is much more useful.

Figure 3-4 portrays the same linkages previously shown in tree format for the lowest echelon, One-on-One. Clearly, the Xs are far easier to count than the lines on the earlier representation.

Figure 3-5 shows the same information at the small unit level.

Figure 3-6 illustrates the relationship at combined arms force level.

Again, the functions represent strict adherence to the notion of the hierarchy and include only those functions involved in managing

ECHELON: SMALL UNIT (COMPANY/PLATOON)

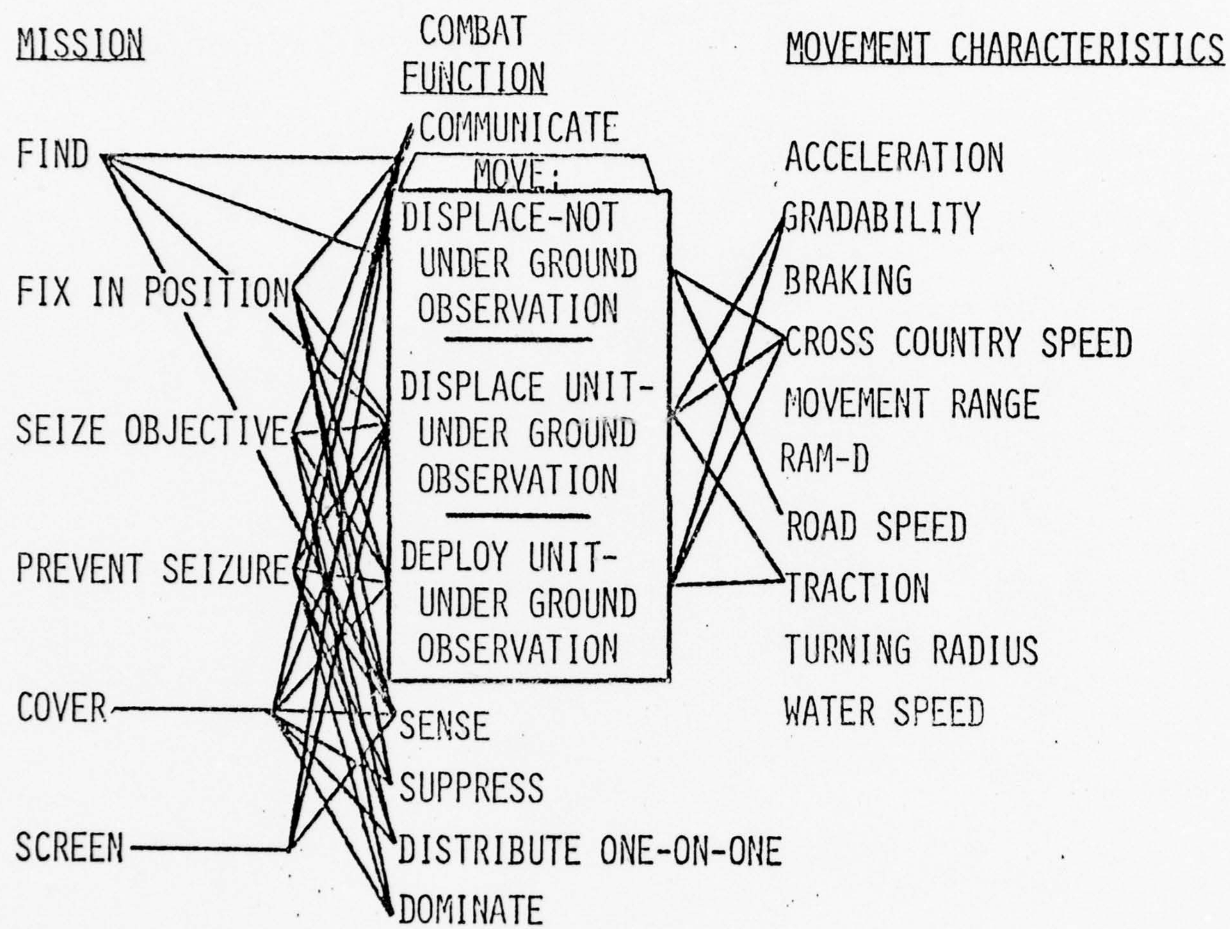

Figure 3-2. Mission/Function/Characteristic Tree 2

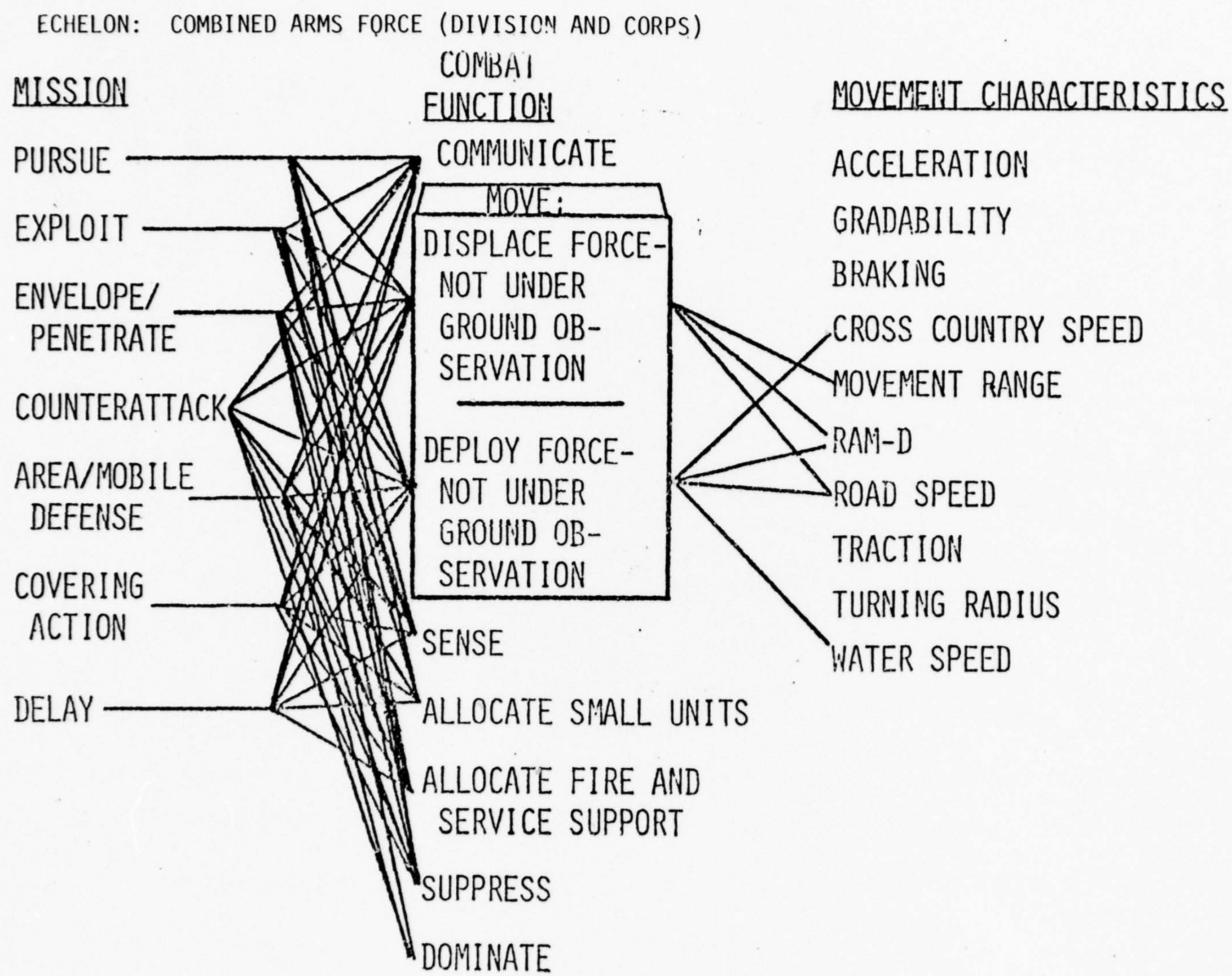

Figure 3-3. Mission/Function/Characteristic Tree 3

ECHELON: INDIVIDUAL VEHICLE IN ONE-ON-ONE COMBAT

MISSION		COMBAT FUNCTION	MOVEMENT CHARACTERISTIC									
DEFEAT	SURVIVE		ACCELERATION	GRADABILITY	BRAKING	CC SPEED	MOVEMENT RANGE	RAM-D	ROAD SPEED	TRACTION	TURNING RADIUS	WATER SPEED
X		ACQUIRE TARGET										
X		TRACK TARGET										
X		SHOOT										
	X	SENSE ATTACK										
	X	EVADE	X	X	X					X	X	
X	X	DISPLACE - UNDER GROUND OBSERVATION		X		X				X		

Figure 3-4. Mission/Function/Characteristic Matrix 1

ECHELON: SMALL UNIT (COMPANY/PLATOON)

MISSION						COMBAT FUNCTION	MOVEMENT CHARACTERISTICS									
FIND	FIX IN POSITION	SEIZE OBJECTIVE	PREVENT SEIZURE	COVER	SCREEN		ACCELERATION	GRADABILITY	BRAKING	CC SPEED	MOVEMENT RANGE	RAM-D	ROAD SPEED	TRACTION	TURNING RADIUS	WATER SPEED
X	X	X	X	X	X	COMMUNICATE										
X				X	X	DISPLACE-NOT UNDER GROUND OBSERVATION				X			X			
X	X	X	X	X	X	DISPLACE UNIT-UNDER GROUND OBSERVATION		X		X				X		
	X	X	X	X		DEPLOY UNIT-UNDER GROUND OBSERVATION		X		X				X		
X	X	X	X	X	X	SENSE										
	X			X		SUPPRESS										
		X	X	X		DISTRIBUTE ONE-ON-ONE										
		X	X			DOMINATE										

Figure 3-5. Mission/Function/Characteristic Matrix 2

ECHELON: COMBINED ARMS FORCE (DIVISION AND CORPS)

MISSION							COMBAT FUNCTION	MOVEMENT CHARACTERISTICS									
PURSUE	EXPLOIT	ENVELOPE/PENETRATE	COUNTERATTACK	AREA/MOBILE DEFENSE	COVERING ACTION	DELAY		ACCELERATION	GRADABILITY	BRAKING	CROSS COUNTRY SPEED	MOVEMENT RANGE	RAM-D	ROAD SPEED	TRACTION	TURNING RADIUS	WATER SPEED
X	X	X	X	X	X	X	COMMUNICATE										
X	X	X	X	X	X	X	DISPLACE-NOT UNDER OBSV.					X	X	X			
X	X	X	X	X	X	X	DEPLOY-NOT UNDER OBSV.				X			X			X
X	X	X	X	X	X	X	SENSE										
X	X	X	X	X	X	X	ALLOCATE SMALL UNITS										
X	X	X	X	X	X	X	ALLOCATE FIRE & SVC SPT										
	X	X	X	X	X		SUPPRESS										
		X	X	X			DOMINATE										

Figure 3-6. Mission/Function/Characteristic Matrix 3

the battle being conducted by subordinate units so that, for the eight functions listed, movement is both necessary and sufficient for only two. The relationship between the function of allocating subordinate small units to combat and movement characteristics are implicit and have been shown in the preceding matrices for lower echelons.

We are now ready to count the linkages that have been established. At Figure 3-7 the pertinent data have been aggregated from the preceding three matrices. Shown for each echelon are the combat movement functions, the number of missions supported by each and a number has been entered in the matrix for every movement characteristic that supports each function. The number of these links has been adjusted to account for the number of missions supported. For example, gradability, supports both "Evade" and "Displace," but "Displace" supports two missions, therefore the total shown for gradability is one for Evade and two for Displace, or a total of three links that connect this movement characteristic with One-on-One missions.

The next higher echelon, small unit, is shown in the same way. The combat movement functions are listed as well as the aggregating function of "Distribute One-on-One" and the number of missions at this echelon that each supports. The summing proceeds in the same way so as to establish the number of links to small unit missions. It will be noted that the number of One-on-One links has been carried down into the "Distribute One-on-One" row but again adjusted to account for the number of small unit missions supported by that function.

The same procedure has again been followed to aggregate to combined arms force level. As above, the number of small unit mission links has been carried down for the "Allocate Small Units" function and again adjusted to account for the number of combined

ECHELON	NR MISSIONS SUPPORTED	COMBAT MOVEMENT FUNCTIONS	ACCELERATION	GRADABILITY	BRAKING	CROSS COUNTRY SPEED	MOVEMENT RANGE	RAM-D	ROAD SPEED	TRACTION	TURNING RADIUS	WATER SPEED
ONE-ON-ONE	1	EVADE	1	1	1					1	1	
	2	DISPLACE UNDER GRD OBSV		2		2				2		
		NR LINKS	(1)	(3)	(1)	(2)				(3)	(1)	
SMALL UNIT	3	DISPLACE NOT UNDER GRD OBSV				3			3			
	6	DISPLACE UNDER GRD OBSV		6		6				6		
	4	DEPLOY UNIT UNDER GRD OBSV		4		4				4		
	3	DISTRIBUTE ONE-ON-ONE	3	9	3	6				9	3	
		NR LINKS	(3)	(19)	(3)	(19)			(3)	(19)	(3)	
CA FORCE	7	DISPLACE NOT UNDER GRD OBSV					7	7	7			
	7	DEPLOY-NOT UNDER				7		7	7			7
	7	ALLOCATE SMALL UNITS	21	133	21	133			21	133	21	
		NR LINKS TOTAL	21	133	21	140	7	14	35	133	21	7

532

Figure 3-7. Mission/Combat Function/Movement Characteristic Relationship

arms force missions supported by this function. The totals at the bottom represent, at least in a qualitative sense, the degree of potential coupling between the movement characteristics and the accomplishment of the combined arms force missions. Again, the caution: these numbers do not indicate the relative importance of the movement characteristics for the accomplishment of the combined arms force missions--only the potential coupling of the individual characteristics to those missions. For example, movement range apparently has only seven links to mission performance, but that coupling is certainly strong if small units run out of fuel before they can be committed to combat.

The results of this calculation are summarized in a different manner at Figure 3-8. The ten movement characteristics are listed at the left. The number of links to missions is shown under each echelon. A blank indicates no coupling to the missions of the lower echelon, but that there is independent coupling to higher echelons to the right. The totals and the corresponding fractions are at the extreme right. Several conclusions can be drawn from such a structure.

- It certainly highlights the complexity of the relationship of movement characteristics to mission performance.
- The higher the number of links for any given characteristic the more complex the relationship and the greater the requirement for analysis.
- The same data portrayed at Figure 3-9 also indicate the echelons that need to be investigated for analysis of each characteristic. The first three need only One-on-One. Gradability and traction need investigation at One-on-One and Small Unit levels. Cross country speed needs to be investigated at all three, road speed at the upper two, and the last three characteristics only at combined arms force level.

MOVEMENT CHARACTERISTIC	ONE-ON-ONE FACTOR	SMALL UNIT FACTOR	CA FORCE FACTOR		NUMBER	(FRACTION)
ACCELERATION	x1	x3	x7	=	21	(.039)
BRAKING	x1	x3	x7	=	21	(.039)
TURNING RADIUS	x1	x3	x7	=	21	(.039)
GRADABILITY	x3	x3	x7			
	-	x10	x7	=	133	(.250)
TRACTION	x3	x3	x7			
		x10	x7	=	133	(.250)
CROSS COUNTRY SPEED	x2	x3	x7			
	-	x13	x7	=	140	(.263)
	-	-	x7			
ROAD SPEED	-	x3	x7			
	-	-	x14	=	35	(.066)
MOVEMENT RANGE	-	-	x7	=	7	(.013)
RAM-D	-	-	x14	=	14	(.026)
WATER SPEED	-	-	x7	=	7	(.013)
			TOTAL	=	532	

Figure 3-8. Potential Effect of Movement Characteristics on Mission Accomplishment - by Echelon

MOVEMENT CHARACTERISTIC	ONE-ON-ONE FACTOR	SMALL UNIT FACTOR	CA FORCE FACTOR		NUMBER	(FRACTION)
ACCELERATION	x1	x3	x7	=	21	(.039)
BRAKING	x1	x3	x7	=	21	(.039)
TURNING RADIUS	x1	x3	x7	=	21	(.039)
GRADABILITY	x3	x3	x7			
	-	x10	x7	=	133	(.250)
TRACTION	x3	x3	x7			
		x10	x7	=	133	(.250)
CROSS COUNTRY SPEED	x2	x3	x7			
	-	x13	x7	=	140	(.263)
	-	-	x7			
ROAD SPEED	-	x3	x7			
	-	-	x14	=	35	(.066)
MOVEMENT RANGE	-	-	x7	=	7	(.013)
RAM-D	-	-	x14	=	14	(.026)
WATER SPEED	-	-	x7	=	7	(.013)
			TOTAL	=	532	

Figure 3-9. Echelons Needed for Analysis

The reader is reminded once more that Figures 3-8 and 3-9 are portrayals of the potential linking of movement characteristics to mission accomplishment. The factors of 140 potential linkages associated with cross country speed or 35 associated with road speed or 21 associated with acceleration and the combined arms force represent the potential linkages with, for example, the accomplishment of a division mission. They in no way, in and of themselves, define division mobility. A comment made at the Tactical Mobility Working Meeting is illuminating in this regard. The comment was, "Do I understand you say the degree of coupling (the hypothesis is being able to accelerate) is important for the combined arms force. Do I understand that, that is the ability of a vehicle to accelerate, is important for the combined armed force mobility?... I have an alternate hypothesis. None of the vehicle characteristics affect at all the mobility in the broad sense of the division or corps." It is precisely this interpretation of the figures that we are trying to avoid. As is indicated, neither acceleration nor cross country speed have direct links to division. Neither have any relationship to the mobility of an entire division or corps in the sense of moving that force up to where it can engage in combat. They do, however, have a direct link to the outcome of either one-on-one engagements or to small unit outcomes and in this sense do influence the outcome of division level combat.

3.1.2 Classification Scheme

The classification scheme developed from this taxonomy is but another, more abstract way of representing the same information shown in tree form at Figures 3-1 through 3-3 and in matrix form at Figures 3-4 through 3-6. It is convenient to build the classification scheme in three increments. The first increment incorproates all of the direct links between movement characteristics and unit missions. The second increment incorporates those indirect links implied by the "Distribute one-on-one" function at small unit level and by the "Allocate small units" function at combined arms force level. The third increment applies to data sources such as performance data useful as inputs to potential links or to effectiveness measures useful as outputs, but which do not, in themselves, close any links between movement characteristics and mission performance.

3.1.2.1 Direct Links

The basic classification scheme for portraying direct links uses a classification number consisting of seven digits in three groups as follows:

1.1.1.1 - 1.1. - 1

Group 1 denotes the link addressed by the reference item in the echelon, movement characteristic, function, mission hierarchy. The same reference may address more than one link--hence have multiple classification numbers.

GROUP 1

Digit 1 - Echelon	Digit 2 - Movement Characteristics	Digit 3 - Function	Digit 4 - Mission
1. One-on-One	1. Acceleration	1. Acquire	1. Defeat
	2. Gradability	2. Track	2. Survive
	3. Braking	3. Fire	
	4. CC Speed	4. Sense Attack	
	5. Movement Range	5. Evade	
	6. RAMD	6. Move UGO*	

*Under ground observation

(Continued)

Digit 1 - Echelon	Digit 2 - Movement Characteristics	Digit 3 - Function	Digit 4 - Mission
	7. Road Speed 8. Traction 9. Turning Radius 0. Water Speed		
2. Small Unit	1. Acceleration 2. Gradability 3. Braking 4. CC Speed 5. Movement Range 6. RAMD 7. Road Speed 8. Traction 9. Turning Radius 0. Water Speed	1. Communicate 2. Displace NUGO** 3. Displace UGO* 4. Deploy UGO* 5. Sense 6. Suppress 7. Distribute One-on-One 8. Dominate	1. Find 2. Fix 3. Seize Objective 4. Prevent Seizure 5. Cover 6. Screen
3. Combined Arms Force	1. Acceleration 2. Gradability 3. Braking 4. CC Speed 5. Movement Range 6. RAMD 7. Road Speed 8. Traction 9. Turning Radius 0. Water Speed	1. Communicate 2. Displace NUGO* 3. Deploy NUGO** 4. Sense 5. Allocate Unit 6. Allocate FS & SS 7. Suppress 8. Dominate	1. Pursue 2. Exploit 3. Envelop/Penetrate 4. Counterattack 5. Area/Mob Defense 6. Covering Action 7. Delay

*Under ground observation.
**Not under ground observation.

Group 2 indicates the kind of information contained in the reference.

GROUP 2

Digit 1 - Data Type	Digit 2 - Type Quantification Technique
1. Performance Measures	None
2. Effectiveness Measures	None
3. Performance Data	None
4. Quantification Techniques	1. Testing 2. Modeling 3. Analytic
5. Trade-offs	None
6. Gaps	None

Group 3 indicates the "value" or thoroughness of coverage of the cited link (Group 1).

GROUP 3

0. Potential But No Actual Coverage*
1. Marginal Value
2. Median Coverage
3. Highly Relevant and Thorough Coverage.

*This entry provides a basis for counting the "lost opportunities."

3.1.2.2 Indirect Links

While the preceding scheme covers the direct links between movement characteristics and mission performance at each echelon, it does not provide for the indirect links subsumed under the functions of "distribute one-on-one" and Allocate small units." These latter functions give rise to the inter-echelon links depicted at Figure 3-10. These indirect links tie all of the links between movement characteristics and the missions of the lower echelon to those missions of the higher echelon to which lower unit performance contributes. This is indicated by the multiplications shown at Figure 3-10.

The classification scheme has been augmented to accommodate these inter-echelon links by using roman numerals as follows. Use I instead of arabic numeral in the second digit of group 1 that designates movement characteristic for those links which go through the DISTRIBUTE ONE-ON-ONE function at small force level, e.g., 2I73 designates the linkages that tie One-on-One performance to mission 3 (seize objective) at small unit level. Use II instead of an arabic numeral in classifying linkages that go through the ALLOCATE function at force level, e.g., 3II61. The entire list of permissible linkages expressed in terms of the classification is shown as follows:

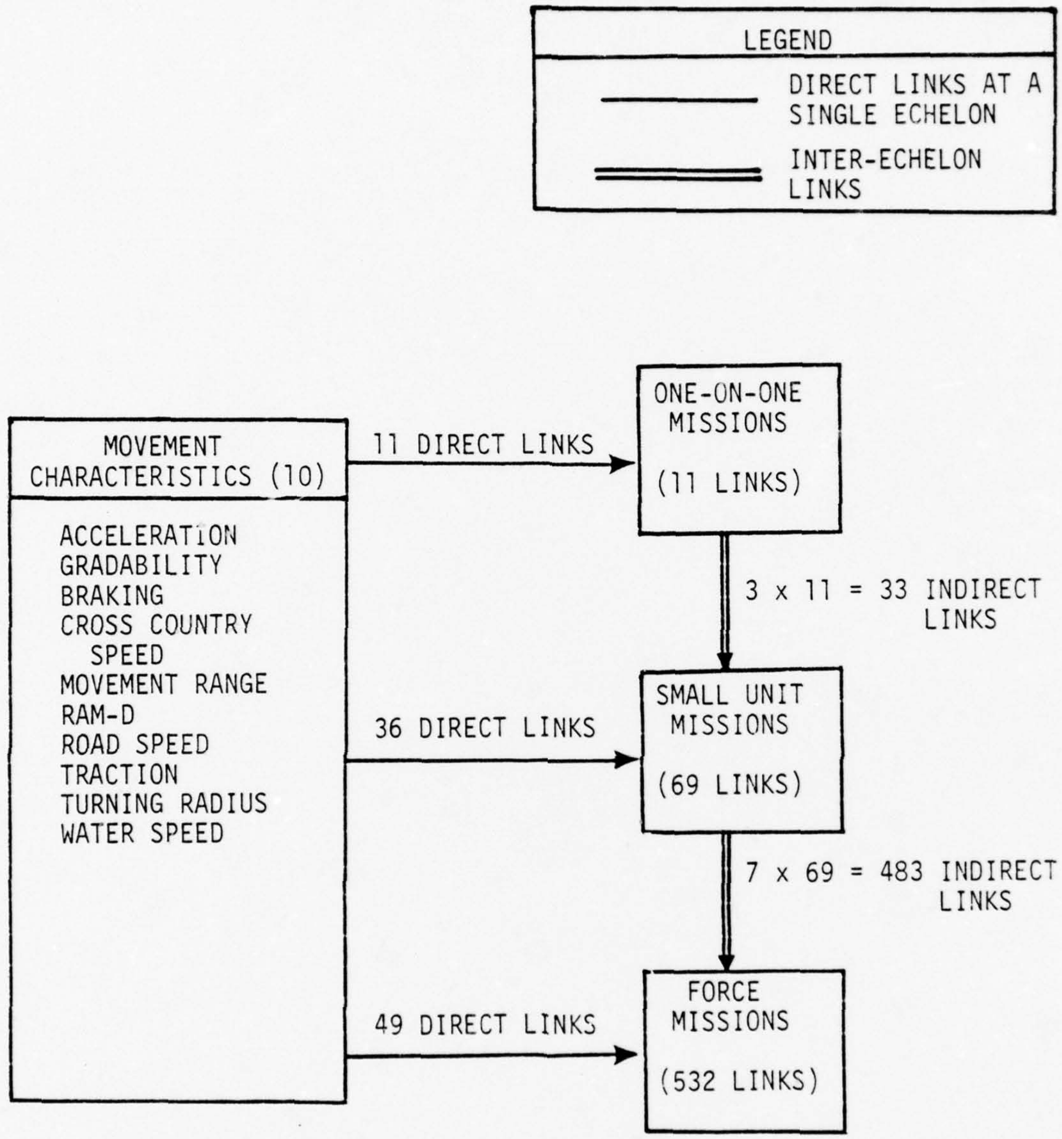

Figure 3-10. Pictorial Representation of Linkages Between Movement Characteristics and Force Missions

ONE-ON-ONE

	NR
1152	1
1252	1
1261	1
1262	1
1352	1
1461	1
1462	1
1852	1
1861	1
1862	1
1952	1
TOTAL	11

SMALL UNIT

	NR
2231	1
2232	1
2233	1
2234	1
2235	1
2236	1
2242	1
2243	1
2244	1
2245	1
2421	1
2425	1
2426	1
2431	1
2432	1
2433	1
2434	1
2435	1
2436	1

PERMISSIBLE LINKS

	NR
2442	1
2443	1
2444	1
2445	1
2721	1
2725	1
2726	1
2831	1
2832	1
2833	1
2834	1
2835	1
2836	1
2842	1
2843	1
2844	1
2845	1
2I73	11
2I74	11
2I75	11
TOTAL	69

FORCE

	NR
3431	1
3432	1
3433	1
3434	1
3435	1
3436	1
3437	1
3521	1
3522	1
3523	1
3524	1
3525	1
3526	1
3527	1

	NR
3621	1
3622	1
3623	1
3624	1
3625	1
3626	1
3627	1
3631	1
3632	1
3633	1
3634	1
3635	1
3636	1
3637	1
3721	1
3722	1
3723	1
3724	1
3725	1
3726	1
3727	1
3731	1
3732	1
3733	1
3734	1
3735	1
3736	1
3737	1
3031	1
3032	1
3033	1
3034	1
3035	1
3036	1
3037	1

	NR
3I151	69
3I152	69
3I153	69
3I154	69
3I155	69
3I156	69
3I157	69
TOTAL	532

3.1.2.3 Non-Linking References

The above list of permissible links is correct insofar as it represents all possible combinations of digits for references that do in fact close the links from mobility characteristics to function to mission for a specified echelon. There are however, many references that pertain but which either do not close any links or close the links only partially. The following extensions in Group 1 are therefore permissible and coded:

First and second digits only:	Denotes that reference contains mobility performance input data only for that echelon
First, second, and third digits only:	Denotes reference which contains links from mobility characteristic to function for that echelon
First, second and fourth:	Denotes reference which relates mobility characteristic directly to mission without explicit functions
First and fourth only:	Reference contains measures of combat effectiveness for specified echelon

Other combinations with omitted digits do not serve any purpose for the mobility study. Do not put a zero into the omitted digit to avoid confusion with mobility characteristic "0"; use a hyphen instead.

3.1.2.4 Application

This classification scheme was used for classifying the literature and for assessing the degree of extant coverage of the various portions of the taxonomy (see Section 4 and Appendix F).

3.1.3 Relative Importance of Links

As has already been stated, the number of links between an individual movement characteristic and combined arms force mission performance is only an indicator of the potential contribution of a single movement characteristic. Some links may be extremely important; others may be so weak as to be insignificant. Certainly the number of links alone is not an adequate basis for assigning priority to

future work. In the absence of quantification techniques adequate for sensitivity analysis, it was necessary to apply judgment as to the value of each potential link. This was accomplished by querying six resident military experts as to the relative importance of each link. A three-tier scheme was used for recording these judgments as follows:

Basis	Rank	Value Assigned
Very Strong Relationship	3	1.0
Normal Strength Relationship	2	0.5
Weak Relationship	1	0.25

The matrices showing the linkages between mission/function/mobility characteristics at Figures 3-4, 3-5, and 3-6 have been modified to reflect these value judgements at Figures 3-11, 3-12, and 3-13, respectively. Appropriate "X" entries in the original matrices have been replaced by the value assigned by the consensus of the military experts. These entries are summarized at Figure 3-14 which lists the resulting value of every permissible link in the classification scheme.

Finally, the assigned values are summarized for each mobility characteristic in the same format as was used in Figure 3-8 which summarized the number of links. This result is displayed at Figure 3-15 which should be compared with Figure 3-8. This table is the primary tool for meeting a number of the objectives stated at the beginning of this section in that it provides a basis for:

- Assessing what is known
- Assessing where the gaps are
- Establishing priorities for filling gaps.

ECHELON: INDIVIDUAL VEHICLE IN ONE-ON-ONE COMBAT

MISSION		COMBAT FUNCTION	MOVEMENT CHARACTERISTIC									
DEFEAT	SURVIVE		ACCELERATION	GRADABILITY	BRAKING	CC SPEED	MOVEMENT RANGE	RAM-D	ROAD SPEED	TRACTION	TURNING RADIUS	WATER SPEED
X		ACQUIRE TARGET										
X		TRACK TARGET										
X		SHOOT										
	X	SENSE ATTACK										
	1	EVADE	1	0.5	1					1	1	
1	1	DISPLACE - UNDER GROUND OBSERVATION		0.5		1				1		

Figure 3-11. Mission/Function/Characteristic Value Matrix 1

ECHELON: SMALL UNIT (COMPANY/PLATOON)

MISSION						COMBAT FUNCTION	MOVEMENT CHARACTERISTICS									
FIND	FIX IN POSITION	SEIZE OBJECTIVE	PREVENT SEIZURE	COVER	SCREEN		ACCELERATION	GRADABILITY	BRAKING	CC SPEED	MOVEMENT RANGE	RAM-D	ROAD SPEED	TRACTION	TURNING RADIUS	WATER SPEED
X	X	X	X	X	X	COMMUNICATE										
1				1	1	DISPLACE-NOT UNDER GROUND OBSERVATION				1			1			
0.5	1	1	1	1	0.5	DISPLACE UNIT-UNDER GROUND OBSERVATION		0.5		1				1		
	1	1	0.5	1		DEPLOY UNIT-UNDER GROUND OBSERVATION		0.5		0.5				1		
X	X	X	X	X	X	SENSE										
	X			X		SUPPRESS										
		1	0.5	0.5		DISTRIBUTE ONE-ON-ONE										
		X	X			DOMINATE										

Figure 3-12. Mission/Function/Characteristic Value Matrix 2

ECHELON: COMBINED ARMS FORCE (DIVISION AND CORPS)

MISSION							COMBAT FUNCTION	MOVEMENT CHARACTERISTICS									
PURSUE	EXPLOIT	ENVELOPE/PENETRATE	COUNTERATTACK	AREA/MOBILE DEFENSE	COVERING ACTION	DELAY		ACCELERATION	GRADABILITY	BRAKING	CROSS COUNTRY SPEED	MOVEMENT RANGE	RAM-D	ROAD SPEED	TRACTION	TURNING RADIUS	WATER SPEED
X	X	X	X	X	X	X	COMMUNICATE										
0.5	0.5	1	1	0.5	1	1	DISPLACE-NOT UNDER OBSV.					1	1	0.5			
0.5	0.5	1	1	0.5	0.5	0.5	DEPLOY-NOT UNDER OBSV.				0.5		1	0.5			0.25
X	X	X	X	X	X	X	SENSE										
0.25	0.5	1	1	1	0.5	0.5	ALLOCATE SMALL UNITS										
X	X	X	X	X	X	X	ALLOCATE FIRE & SVC SPT										
	X	X	X	X	X		SUPPRESS										
		X	X	X			DOMINATE										

Figure 3-13. Mission/Function/Characteristic Value Matrix 3

ONE-ON-ONE

	NR	VALUE
1152	1	1
1252	1	0.5
1261	1	0.5
1262	1	0.5
1352	1	1
1461	1	1
1462	1	1
1852	1	1
1861	1	1
1862	1	1
1952	1	1
TOTAL	11	9.5

SMALL UNIT

	NR	VALUE
2231	1	0.25
2232	1	0.5
2233	1	0.5
2234	1	0.5
2235	1	0.5
2236	1	0.25
2242	1	0.5
2243	1	0.5
2244	1	0.25
2245	1	0.5
2421	1	1
2425	1	1
2426	1	1
2431	1	0.5
2432	1	1
2433	1	1
2434	1	1
2435	1	1
2436	1	0.5
2442	1	0.5
2443	1	0.5
2444	1	0.25
2445	1	0.5
2721	1	1
2725	1	1
2726	1	1
2831	1	0.5
2832	1	1
2833	1	1
2834	1	1
2835	1	1
2836	1	0.5
2842	1	1
2843	1	1
2844	1	0.5
2845	1	1
2I73	11	9.5
2I74	11	4.75
2I75	11	4.75
TOTAL	69	43

FORCE

	NR	VALUE
3431	1	0.25
3432	1	0.25
3433	1	0.5
3434	1	0.5
3435	1	0.25
3436	1	0.25
3436	1	0.25
3521	1	0.5
3522	1	0.5
3523	1	1
3524	1	1
3525	1	0.5
3526	1	1
3527	1	1
3621	1	0.5
3622	1	0.5
3623	1	1
3624	1	1
3625	1	0.5
3626	1	1
3627	1	1
3631	1	0.5
3632	1	0.5
3633	1	1
3634	1	1
3635	1	0.5
3636	1	0.5
3637	1	0.5
3721	1	0.25
3722	1	0.25
3723	1	0.5
3724	1	0.5
3725	1	0.25
3726	1	0.5
3727	1	0.5
3731	1	0.25
3732	1	0.25
3733	1	0.5
3734	1	0.5
3735	1	0.25
3736	1	0.25
3737	1	0.25
3031	1	0.125
3032	1	0.125
3033	1	0.25
3034	1	0.25
3035	1	0.125
3036	1	0.125
3037	1	0.125
3I151	69	10.75
3I152	69	21.5
3I153	69	43
3I154	69	43
3I155	69	43
3I156	69	21.5
3I157	69	21.5
TOTAL	532	228.125

Figure 3-14. Values Assigned to Permissible Links

MOVEMENT CHARACTERISTIC	ONE-ON-ONE FACTOR	SMALL UNIT FACTOR	CA FORCE FACTOR		RELATIVE VALUE	FRACTION	RANK
TRACTION	x3	x2 x8.5	x4.75) x4.75)	=	68.88	.3019	1
CROSS COUNTRY SPEED	x2	x2 x9.75	x4.75) x4.75) x2.25)	=	67.55	.2961	2
GRADABILITY	x1.5	x2 x4.25	x4.75) x4.75)	=	34.44	.1510	3
ROAD SPEED		x1.5	x4.75) x5)	=	12.13	.0532	4
RAM-D			x10	=	10.00	.0438	5
ACCELERATION	x1	x2	x4.75	=	9.50	.0416	)
BRAKING	x1	x2	x4.75	=	9.50	.0416	) 6, 7, 8
TURNING RADIUS	x1	x2	x4.75	=	9.50	.0416	)
MOVEMENT RANGE			x5.5	=	5.50	.0241	9
WATER SPEED			x1.125	=	1.125	.0049	10

Figure 3-15. Relative Value of Movement Characteristics to Combined Arms Force Mission Accomplishment

The reader is reminded that this is only a zero order approximation as to the relative value of the movement characteristics considered to the mission accomplishment of the successive levels. It is being used only to determine which of these links should be explored and quantified first by means of more precise techniques. As soon as such results become available they should, of course, be substituted for the structured judgment values depicted at Figure 3-15.

3.2 LITERATURE SEARCH

In order to provide the basis for the analysis and synthesis as described herein, a literature search was conducted to discover and record relevant reports, analyses and other documentation relating to tactical mobility work completed and/or on-going. Documents were obtained and/or reviewed from the following sources:

- Research visits to selected Army/DoD agencies (e.g., USA Concepts Analysis Agency, Army War College, Industrial College of the Armed Forces and National War College)
- Mobility collection of ODUSA(OR)
- Defense Documentation Center (DDC) listings
- Personal knowledge and contacts of study team members
- Report of Proceedings of the Working Meeting.

During the initial period of the literature search, pertinent extracts of mobility related data/information were made on the basis of an intuative feeling of the value of the data/information. During the latter stages, this process was assisted by the taxonomy and classification scheme previously described.

The results of the initial literature search were distributed in booklet form* to all participants in the Working Meeting for use as

*"The Qualitative and Quantitative Value of Tactical Mobility, Initial Literature Search Synthesis;" SAI, July 1977.

a basis for meeting discussions. This booklet contains all extracts made prior to the meeting classified as to "kind of information" contained therein and a bibliography.

Extracts for the entire literature search were made and coded as described in paragraph 3.1, above. These together with a biloiography cross-indexed as to:

- Author
- Corporate Author
- Kind of Information (e.g., Performance Measures)
- Echelon (e.g., "One-on-One").

are presented in Appendix A to this report. While there are undoubtedly some "gems of wisdom" in such sources as unpublished monographs, no attempt was made to search these out in view of the time required to evaluate their potential contribution and then introduce that contribution into the reasonably recent body of official knowledge which was the primary search objective. In that this source type does not provide an "active input," this restriction is not considered significant in terms of this study.

3.3 WORKING MEETING

As a part of the effort to determine the current "state of knowledge" pertaining to tactical mobility, a three day working meeting was held at the National War College, Fort McNair, Washington, D.C., 26-28 July 1977. The meeting objectives were to develop a better understanding of the quantitative and qualitative value of tactical mobility, with emphasis on the mobility of firepower as it pertains to ground combat vehicles (this objective pertained to all participants), and, for SAI, to serve as a data and thought source for the overall study effort. Attendees were selected in coordination with the study sponsor from the "tactical mobility" community, with emphasis placed on personnel actively working the problem.

The meeting was structured around three working groups oriented on the individual vehicle in one-on-one/n combat, the small tactical unit, and the combined arms force (large unit) respectively. Following an opening general session, these groups, in separate working sessions, developed assessments which were then presented to the full group at a closing general session. As a part of its on-going mobility contract work, Science Applications, Inc. (SAI) presented to the full group at the opening session, the results of its investigations to date consisting principally of a taxonomy for structuring mobility related tasks and characteristics, and a synthesis of a literature search in the form of an analysis and a compendium of extracts, a copy of which was provided to each participant.

Issues (objectives) addressed consisted of the following:

- How should tactical mobility be defined for an individual vehicle in one-on-one combat? (...for a small unit/combined arms force?)
- What mobility measures of performance are appropriate for this echelon?
- What is the relationship between mobility performance and the other performance characteristics of a fighting vehicle (small unit/combined arms force)? What trade-offs are meaningful?
- What are appropriate measures of effectiveness for an individual vehicle in one-on-one combat (...for a small unit/combined arms force)? Can they be used as inputs for the small unit level?
- Do transforms (models) exist for quantifying the MOEs?
- What has been done to measure the effectiveness of tactical mobility of individual vehicles in one-on-one combat? (One-on-"n") (...of a small unit/combined arms force?)

- What are the data, testing, and analysis gaps?

- What should be done to measure the effectiveness of tactical mobility of individual vehicles in one-on-one combat? (...of small units/combined arms forces)

- How does the sum of the foregoing contribute to the meeting objective (determining the value of tactical mobility?)

A "Report of Proceedings"* was published by SAI and distributed to all participants. This report includes major findings and observations, transcripts of opening and closing remarks, question and answer sessions, formal presentations, and a record of individual work group sessions. The executive summary of this report is included as Appendix D to this report.

*"Tactical Mobility Working Meeting, Report of Proceedings," SAI, 26 August 1977.

Section 4

APPLICATION OF THE TAXONOMY

4.1 PURPOSE

This section summarizes how the taxonomy was applied to the literature search to identify tactical mobility literature concentration and gaps. Detailed numerical results and analyses are found in Appendix F, Analysis and Synthesis. Two potential applications of the taxonomy are discussed at the end of this section (4.4 and 4.5).

4.2 CLASSIFICATION OF LITERATURE REFERENCES ACCORDING TO TAXONOMY ELEMENTS

The basic classification elements of the taxonomy are Level or Echelon (e.g., One-on-One), Movement Characteristics (e.g., Acceleration), Combat Function (e.g., Evade) and Mission (e.g., Defeat). The literature references were represented by extracts chosen to typify key portions of the reference document. These extracts were individually examined for the presence of the classification elements cited above. A single extract could represent potential coverage of all echelons, movement characteristics, combat functions, and missions. Likewise an extract could have no portion of the taxonomy present. The individual classifications of reference extracts were combined to represent what portions of the taxonomy the reference covered, either potentially or deliberately.

4.2.1 Potential Presence

The above process generated classifications that the literature could have covered. Where there was doubt, a judgment was made based on the best available information as to level, movement characteristics, combat functions and missions to be included in classification.

4.2.2 Deliberate Coverage

The fact that a classification element was potentially present did not mean that it was covered or, specifically, that the influence of movement characteristics were related to mission performance. Two more steps had to occur before this was determined. First, it had to be decided whether the classification elements potentially present in a reference formed links from movement characteristics to combat functions to mission performance for given echelons. When this application of the taxonomy was performed, the absence of any links in a reference indicated that while the coverage of the elements of the classification that were present may have been thorough, the results could not provide information on how movement characteristics impact on mission performance. Where links were discovered to be present, the potential for addressing the value of tactical mobility (at least in part) was established. The second step was to evaluate the potential. This meant that the value of the information and kind of information had to be established.

4.3 USE OF THE LINKAGE CONCEPT

4.3.1 Links Potentially Present

The taxonomy provides for 11 direct links at the One-on-One level, 36 direct links at Small Unit level, and 49 direct links at Combined Arms Force level: 96 in all. A single reference could have potentially addressed all of them. All 96 were potentially present when all of the literature was taken into account.

4.3.2 Links Deliberately Addressed

When the links were evaluated as to kind of information and thoroughness of coverage, the tactical mobility literature is seen to be concentrated on a portion of One-on-One level mission performance. The impact of movement characteristics on high level mission performance has little or no coverage.

4.3.2.1 Thoroughness of Coverage

Of approximately 300 documents considered, 70 were judged as having the potential for supplying information (i.e., forming links) regarding the qualitative and quantitative value of tactical mobility. Of the 70 documents which had potential elements of the taxonomy present, 42 references provided a sufficient combination to form at least one of the 96 possible direct links. When this coverage was evaluated to determine whether the link was thoroughly and relevantly covered, covered at a median level, marginally covered or a missed opportunity (i.e., potentially present but not covered), the breakout of all 96 links occurs as in Table 4-1.

Table 4-1

COVERAGE OF 96 DIRECT LINKS BY MOBILITY LITERATURE*

LEVEL	POSSIBLE LINKS	THOROUGH COVERAGE	MEDIAN COVERAGE	MARGINAL COVERAGE	MISSED OPPORTUNITIES
One-on-One	11	10	0	1	0
Small Unit	36	7	6	7	16
C/A Force	49	6	4	10	29
	96	23	10	18	45

* All 96 links are potentially present in the literature.

When the 23 thoroughly covered links are investigated according to how many references addressed them, the breakout occurs as in Table 4-2.

Table 4-2

FREQUENCY OF THOROUGH COVERAGE

LEVEL	HIGHLY RELEVANT LINKS	ONE REFERENCE ONLY	TWO REFERENCES	THREE REFERENCES	FOUR REFERENCES	FIVE OR MORE REFERENCES
One-on-one	10	3	0	1	1	5
Small Unit	7	6	1	0	0	0
C/A Force	6	5	1	0	0	0

The One-on-One links addressed in five or more references were also the most frequently addressed links without regard to coverage. They are shown in Figure 4-1 in order of frequency.

Level	Movement Characteristic	Combat Function	Mission
One-on-One	Acceleration	Evade	Survive
One-on-One	Cross Country Speed	Move UGO*	Survive
One-on-One	Cross Country Speed	Move UGO*	Defeat
One-on-One	Traction	Evade	Survive
One-on-One	Turning Radius	Evade	Survive

* Under ground observation.

Figure 4-1. Five Most Frequently Addressed Links

From the tables it is apparent that the most concentration of the literature is at the One-on-One level of combat. The five most frequent links reflect a concern with the issue of the trade-off of mobility/agility for increased armament to gain survivability.

4.3.2.2 Kind of Information

Links which were found in two or more references with median coverage or better were reviewed for the kind of information that the coverage represented. The kind of information categories are stated in Figure 4-2 below.

PERFORMANCE MEASURES
EFFECTIVENESS MEASURES
PERFORMANCE DATA
TESTING
MODELING
ANALYTIC
TRADE-OFFS
GAPS

Figure 4-2. Kinds of Information

The dominant coverage occurred for the first three of the five most frequent links shown in Figure 4-1. Performance measures in general were slighted by the literature. Gaps were not at all covered by literature which addressed links in two or more references with median or better coverage. On the other hand, references which did not form links did address gaps. In reviewing links found in the literature together with the kind of information covered, there appeared to be a basic neglect of relating movement characteristics to combat outcome above the One-on-One level.

The concentration of mobility literature that fits the taxonomy is on about 3% of all 96 direct links. However, about one-third (or 33) direct links have potentially high coupling-to-mission performance. The above three links are included in the 33. On the basis of best payoff, the mobility literature appears concentrated on less than 10% of those portions of the taxonomy where the potential influence is high. The impact of gradability on survival at the One-on-One level, Cross Country Speed, Road Speed, and traction on Small Unit mission performance and movement range and RAM-D on Combined Arms Force performance is neglected. There is some conflict in the literature regarding the trade-off of armor protection for agility. Some analyses are showing an increase in survivability; others a decrease. This needs to be resolved and perhaps the key is how much cost-effective power increase can accompany the increase in armor protection.

4.3.3 Areas Lacking Coverage

In many cases the evaluation process did not give credit for the influence of movement characteristics above the One-on-One level. While the literature did reflect some effort to simulate or analyze combat above the One-on-One level, there was rarely a mechanism to measure mission performance at small unit and force levels. A notable exception to this trend was the XM-1 COEA (Reference 25). Another way of examining this is Table 4-3. This table compares the likely payoff

Table 4-3

WEIGHTED COVERAGE VERSUS PAY-OFF POTENTIAL

MOVEMENT CHARACTERISTIC	ONE-ON-ONE		SMALL UNIT		COMBINED ARMS FORCE	
	INDEX OF PAYOFF POT'L	INDEX OF W'TD COV'G	INDEX OF PAYOFF POT'L	INDEX OF W'TD COV'G	INDEX OF PAYOFF POT'L	INDEX OF W'TD COV'G
Traction	1	18	6	3	30	
Cross Country Speed	1	22	6	8	30	6
Gradability	1	2	3	2	15	
Road Speed			1	2	5	9
RAM-D					4	2
Acceleration	0.5	14	1		4	
Braking	0.5	2	1		4	
Turning Radius	0.5	8	1		4	
Movement Range					2	1
Water Speed					0.5	
Total	4.5	67	19	15	100	18

of investigating movement characteristics influence on mission at each echelon with the relative coverage of that influence. The derivation of the indices is discussed in greater detail at Appendix F. Table 4-3 shows that the potential payoff and the actual coverage vary inversely. But it must be realized that this does not argue against the value of the lower level coverage. Certainly, lower level analysis of tactical mobility is a necessary prelude to higher level work.

4.4 POTENTIAL APPLICATION OF TAXONOMY FOR TRADE-OFF ANALYSIS

4.4.1 Trade-offs within the Taxonomy (i.e., within Movement Characteristics

4.4.1.1 Trade-offs within Levels of Combat

The judgmental assessment of relative importance of the links in terms of potential influence on mission performance provides a place to start investigation of what can be given up in terms of movement characteristics to gain pay-off elsewhere. A further clue is those movement characteristics which are unique to a given level. Table 4-4 displays movement characteristics by echelon. The numbers in the table represent numbers of links involved.

Table 4-4

NUMBER OF LINKS AT EACH LEVEL OF COMBAT
BY MOVEMENT CHARACTERISTICS

	ONE-ON-ONE	SMALL UNIT	C/A FORCE
Acceleration	1		
Gradability	3	10	
Braking	1		
Cross Country Speed	2	13	7
Movement Range			7
RAM-D			14
Road Speed		3	14
Traction	3	10	
Turning Radius	1		
Water Speed			7

The circled instances represent cases where all of the links involved were judged not to have a high coupling to mission performance. Note that one of them (water speed) is unique to the combined arms force level of combat. None of the water speed links was judged to have even a medium influence on mission performance. Thus in the taxonomy a potential mobility area has been identified for trading to get pay-off elsewhere. Movement range and RAM-D are also unique to force level combat performance. Each of these latter characteristics has some links having a highly rated pay-off in combat mission performance. Thus the taxonomy has provided an indicator for a potential investigation of the impact of a lowered requirement for water speed in lieu of a higher requirement for movement range or RAM-D (or both).

4.4.1.2 Trade-Offs Across Levels of Combat

As a first insight the taxonomy indicates an area that is not a good candidate for trade-off, i.e., cross country speed. It has an effect on combat outcome at all levels of combat although its influence at the force level was rated marginal. On the other hand gradability was rated as having no more than a medium influence on

one-on-one or small unit combat outcomes. This indicates an area for potential investigation of a lowered requirement for gradability to pay for increased characteristics elsewhere such as cross country speed. This might be translated in terms of engineering requirements as a trade-off of low end transmission performance for high end transmission performance. In that regard the influence on acceleration would have to be taken into account. It must be remembered the impact of cross country speed on small unit mission performance has been, so far, neglected. Its influence in terms of attrition ratios at the small unit level has largely been to produce no change in outcome. As a final insight on trade-offs across combat levels the indirect links must be considered. The indirect links provide a cascading effect in carrying the effect of combat performance along a link at one level to the next higher level. Thus in general one must be wary in trading off combat performance at the one-on-one level to get better performance of some link at force level. Reduction of one-on-one performance can reflect greatly on force performance in an active combat situation. The concentration of the literature at the One-on-One level is therefore not criticized because that level is unimportant. It is important. The criticism is that the higher level direct linkages have been generally neglected.

4.4.2 Extension of the Taxonomy to Other Than Movement Characteristics

The taxonomy was initiated as a mechanism for relating movement characteristics to tactical accomplishment. It serves to structure and provide insight on the complexities of the tactical mobility problem. An additional purpose was to establish a basis for trade-offs. Some potential trade-off considerations have been discussed in the foregoing paragraphs. A remaining problem of trade-offs is the sacrifice or enhancement of movement characteristics for improvement or at the expense of other characteristics. Some of the literature has dealt with this aspect but in an isolated fashion.

It has already been remarked that much of the literature reflects a concentration on the issue of the trade-off of mobility, agility for increased survivability. The comment that this has been done in an isolated fashion means that this trade-off has been considered at the one-on-one level for not only movement characteristics but also other characteristics such as survival and firing. Each of these may have reverberations felt in terms of small unit and force level combat outcomes. Before such trade-offs can truely be finalized taxonomies mapping out the complexities of other characteristics than movement need to be established. Figure 4-3 cites other characteristics for which taxonomies need to be established. There may be other factors.

COMMAND AND CONTROL
COMMUNICATION
FIRING
SURVIVABILITY
HUMAN FACTORS
INTELLIGENCE
TARGET ACQUISITION
SUPPORT
TRAINING
DOCTRINE

Figure 4-3. Other Combat Factors Needing a Taxonomy

The establishment of such taxonomies should not be difficult in light of the present one covering movement. Combat functions and missions have already been established together with their links at each echelon. The only new effort involved is to identify the subordinate characteristics of each factor in Figure 4-3, their relationship with combat functions by level of combat and the

interrelationship among factors. Such an effort is beyond the scope of the present research but is judged as being necessary prior to a meaningful development of trade-offs.

4.5 POTENTIAL APPLICATION OF THE TAXONOMY FOR FILLING GAPS

In Appendix F the process of integrating the classification of extracts of a given reference was described. In the example shown a synergistic effect was realized in that two or more extracts could provide more information on links (at least potentially) than each extract taken singly. It was investigated whether this concept could be applied to combine results of individual references. It was tried. In combining the separate classifications of all of the literature all 96 direct and indirect links were produced. Thus the body of literature potentially covers the mobility taxonomy. However, in trying to cross walk from one reference to another, the objective of realizing full value and full coverage of the information was not realized. Part of the problem was the narrowed scope of any single reference and the fact that the references were themselves only representations and interpretations of a data base. Another approach would be to use the taxonomy to investigate the data base directly.

4.5.1 Tool For Organizing a Data Base Search

An application of the taxonomy directly to the data base, particularly the testing data base would undoubtedly be fruitful. It would avoid the issue encountered in the classification process of interpreting an author's meaning for mobility or agility in terms of movement characteristics. It should produce a more accurate classification of the presence of movement characteristics in the work done. It should be amenable to combination in the manner described above leading to some new analyses or recommendations for new gap filling research.

Section 5

DISCUSSION

5.1 INTRODUCTION

The results of the analysis and synthesis of data derived from the literature search and the Mobility Working Meeting are discussed in this section under headings that address each of the issues listed at paragraph 2.6. One additional issue addressed by the working groups at the Working Meeting was the question of defining tactical mobility. That definition has already been developed in Paragraph 2.5. Other findings are summarized at the end of this section.

5.2 MOBILITY PERFORMANCE MEASURES

5.2.1 One-on-One

As could be expected at this level, the One-on-One work group concentrated heavily on measures of performance, which for the individual vehicle, are closely related to movement characteristics and are more amenable to measurement than measures of effectiveness. At this point it should be noted that many, and probably a majority, of the personnel who have been and are working the mobility problem are basically engineers (e.g., in the WES, TARADCOM organizations) and are therefore tuned to the problems of engineering design as opposed to mission effectiveness. This bias--which is not meant in a denegrating sense--resulted in the establishment of two classes of measures of performance, viz., "operational" and "engineering." This may be a useful distinction in terms of focusing future work on what is actually being attempted in test, analysis and experimentation programs. In any event, a relationship between the two was recognized which is shown in Figure 5-1 below. This figure also lists the MOP which were considered applicable to the one-on-one level.

OPERATIONAL MOP	ENGINEERING MOP			
	GO-NO GO	X-COUNTRY	AGILITY	CREW PERF
• THREAT PERFORMANCE DEGRADATION				
- SPEED		X		X
- EVASIVENESS			X	X
• EXPOSURE TIME				
- SPEED		X	X	X
- ROUTE SELECTION	X			
• FIRING ABILITY				
- ON MOVE		X		X
- QUICK HALT			X	X
- POSITION SELECTION	X			

Figure 5-1. Relationship of Engineering and Operational MOP (One-on-One/N)

The concept of "threat (system) performance degradation" as an MOP is also useful in illuminating the survivability ("survive") mission, in that it provides a baseline (i.e., the theoretical performance of a threat system) and measurable parameters (e.g., degradation in hit probability due to speed or evasiveness or both).

While not a measure of performance, it should be noted that the group stressed "crew performance" as a movement characteristic and added that to the list presented by SAI. It was recognized that this was not a true movement characteristic, but the interaction of vehicle/system performance and the ability of the crew to function effectively was felt to be so important that it was added to the list.

5.2.2 Small Unit

The Tactical Mobility Working Meeting Work Group for Small Units developed seven measures of performance which are listed in Figure 5-2.

1. SPEED MADE GOOD BETWEEN TWO POINTS ON THE TERRAIN
2. PERCENT OF UNIT REACHING OBJECTIVE IN A SPECIFIED TIME OR LESS
3. AVERAGE SPEED
4. PROBABILITY OF BEING ABLE TO TRAVEL A STRAIGHT LINE PATH BETWEEN TWO RANDOMLY SELECTED POINTS WITHOUT ENCOUNTERING ANY IMPASSE
5. AREA DENIED
6. RATE OF CHANGE OF LINE-OF-SIGHT TO FIRE
7. RATE OF CHANGE OF VELOCITY VECTOR

Figure 5-2. Tactical Mobility Working Meeting Proposed Mobility MOP at Small Unit Level

Each will be discussed together with other factors in order to develop a synthesized set.

5.2.2.1 Speed Made Good Between Two Points on the Terrain

Implicit in this measure is the idea of moving between two points, A and B, along an infinite number of possible paths. The points A and B will generally not be random for small unit combat and will at best represent constrained choice. The proposed measure implies the straight line displacement divided by the time taken to accomplish the displacement. In Figure 5-3 is a possible application of this measure.

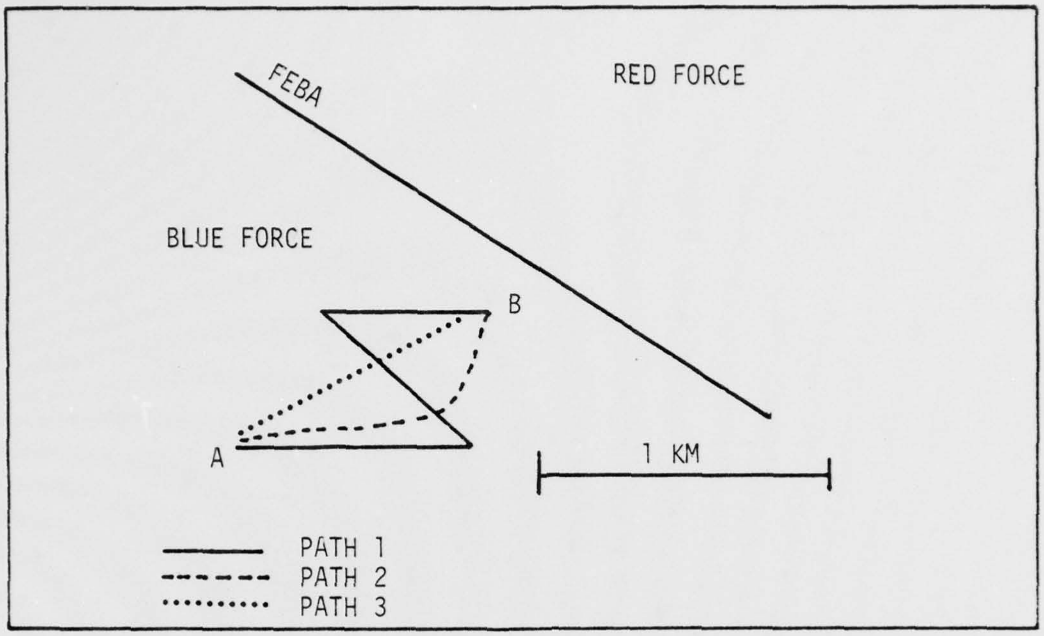

Figure 5-3. Speed Made Good Application

Elements of a blue force small unit must move from point A to point B to defend the FEBA as shown. It is assumed that their movement can be observed. Hence it is prudent to minimize the time required to close the distance AB. Three paths are shown which place progressively, from path 1 to 3, more demands on movement characteristics. Path 1 is approximately 2.1 kilometers, essentially along the road net. Path 2 is approximately 1.4 kilometers along open country. Path 3 is 1 kilometer and along rugged terrain. Consider the following three vehicles which have average speeds along each path as shown in Table 5-1.

Table 5-1

AVERAGE SPEEDS (KM/HR) ALONG PATHS

PATH	VEHICLE 1	VEHICLE 2	VEHICLE 3
1	40	35	30
2	50	32	30
3	Cannot Traverse	15	20

Associated with the average speed and path length are the displacement time in minutes shown in Table 5-2 required to close the distance.

Table 5-2

MINUTES TO TRAVERSE FROM A TO B

PATH	VEHICLE 1	VEHICLE 2	VEHICLE 3
1	3.15	3.50	4.20
2	3.36	2.63	2.90
3	-	4.00	3.00

The minimum time vehicle is Vehicle 2 along path 2, although Vehicle 3 is not significantly different along path 2 and does significantly better in more rugged terrain. If it is considered that more rugged terrain denies observation partially it enhances the value of vehicle 3 more. In any case the measure of performance is appropriate for small unit situations and is currently being used in modified form (Army mobility model).

5.2.2.2 Percent of Unit Reaching Objective in a Specified Time or Less

This measure can tie in with the influence of changes in movement characteristics on small unit mission outcome. As such it

is applicable to an area which in Section 4 was shown to be mostly neglected by the literature. It is regarded as a good measure. However, it is more in the category of being a measure of effectiveness of unit performance as a result of movement characteristics as well as a result of the characteristics of other factors. Thus it should be retained but as a measure of effectiveness.

5.2.2.3 Average Speed

This measure of vehicle performance is a necessary input for deriving the first measure of performance (speed made good) and therefore must be known in relation to type environmental conditions.

5.2.2.4 Probability of Being Able to Travel Between Two Randomly Selected Points Without Encountering An Impasse

The notion behind this measure is that as the probability goes up the more the small unit commander can consider by way of options in moving his elements to accomplish his mission. As seen in the hypothetical example in Figure 5-3, Table 5-1 and Table 5-2, Vehicle 1 could not negotiate path 3. Minimizing time may not be the best solution to a given combat problem where the movement is under ground observation. Minimizing the time during which the vehicle is observed may dominate. This measure should be used together with the first measure as exposing options available to small units in displacing and deploying.

5.2.2.5 Area Denied

This measure is similar to the second measure in that it is essential as a measure of an important area neglected by the literature but is more properly a measure of unit effectiveness as a result of movement characteristics as well as the characteristics of other factors.

5.2.2.6 Rate of Change of Line-of-Sight to Fire, Rate of Change to Velocity Vector (Measures 6 and 7)

In the tactical mobility literature (Reference 25) it was shown that the apparent motion variables explained a significantly larger portion of the variance observed in dependent variables (such as gunner error variables) than did absolute motion variables. In other work (Reference 2 as well as 25) these apparent motion variables are defined as line of vehicle position x minus line of aim γ equals Lay error L. Target speed $\dot{x}$ minus tracking rate $\dot{\gamma}$ equals tracking error R. Apparent target acceleration $\ddot{x}$ minus apparent gun acceleration $\ddot{\gamma}$ equals rate of change of tracking error R. These get to the heart of the issue which the measures being considered are addressing. In any case they are all more appropriate to the One-on-One combat level rather than small unit level.

5.2.2.7 Are Other Measures Needed?

From the taxonomy, there are four movement characteristics which can impact directly on mission performance at the Small Unit level. These are gradability, cross country speed, road speed and traction. Cross country speed and road speed are already encompassed in the measures above which pertain to the travel of vehicles between two points to accomplish unit missions, although road speed was not judged, by itself, as having a high impact on small unit performance. Gradability also was not judged to impact highly on small unit mission performance. Traction in many cases was judged to have a potentially high impact on small unit mission performance (as well as at the one-on-One level). Thus a measure of performance that relates to traction could be useful. As has already been stated the movement characteristics are not independent. The two measures (1 and 4) discussed above which deal with movement performance between two points implicitly will increase with traction as well as with cross country speed, road speed, and gradability. It is judged that the two measures would be sensitive to separate changes in the

four germane movement characteristics at the small unit level and thus are sufficient.

5.2.2.8 Summary of Measures of Performance for the Small Unit Level

MOP 2 and 5 were found to be more appropriately measures of small unit effectiveness. MOP 6 and 7 were found to be more appropriately one-on-one measures of performance and modified as shown in 5.2.2.6. 1 and 4 are regarded as sufficient and include as inputs gradability, cross country speed, road speed and traction. In this sense 3 is more properly an input. The foregoing is summarized in Figure 5-4.

INPUT MEASURES OF PERFORMANCE

GRADABILITY

CROSS COUNTRY SPEED

ROAD SPEED

TRACTION

OUTPUT MEASURES OF PERFORMANCE

TRAVEL BETWEEN TWO POINTS

- PROBABILITY OF SUCCESS WHEN POINTS ARE RANDOMLY SELECTED
- SPEED MADE GOOD WHEN POINTS ARE COMBAT DEPENDENT

Figure 5-4. Mobility Measures of Performance at Small Unit Level

5.2.3 Combined Arms Force

Mobility performance measures should be derivable from the definition of tactical mobility. The definition established at paragraph 2.5 is adequate for this purpose with one exception. That definition, i.e., mission-related movement capability of the force, does not explicitly contain the notion of the support functions which become an inherent part of the mission at the combined arms force level. At this level, one is concerned not only with the capability to move combat power but also with the capability to sustain it.

If one looks at the different postures assumed by a combined arms force in order to effect movement these postures or modes of movement fall into three classes:

- Administrative March - Movement when contact with the enemy is not imminent.
- Approach March - Movement when contact with the enemy is imminent.
- Maneuver - Movement (and fire) in the face of the enemy.

Of these three modes of movement, the last, maneuver, is not really commensurable in terms of the tactical mobility of the force as a whole because force movement is being constrained by the enemy and the ability of the force to move is dependent as much or more on its ability to fight than on its capability to move. Even then, its movement capability may also be constrained by the mobility of elements of the force not in contact as is demonstrated in the development at paragraph E.2, Appendix E. Therefore, while it is appropriate to measure the mobility of the component parts of a combined arms force that is maneuvering, it is not meaningful to develop a mobility performance measure for the entire force in contact. Such a measure is really an effectiveness measure.

On the other hand, a mobility performance measure for a combined arms force not in contact, i.e., engaged in administrative or an approach march, is appropriate and was developed by the Combined Arms Force Working Group at the Mobility Working Meeting. That development is as follows:

<u>Elements of mobility in move to point of contact role</u>

- Decision to Move
- Communication of the Decision

- Organization
  - Coordination
  - Supply
- Movement
  - Moving
  - Route Clearance
  - Protection (Against Air and Artillery)
  - RAM-D
- Control
- Deployment

Clearly, there exist many measures that can quantitatively describe the "degree of mobility capability" possessed by a combined arms unit. One that appears to capture the ideas inherent in the qualitative definition is:

$$M_{ij} = \frac{\sum_k n_k}{B_{ij}(n_k)} \qquad (1)$$

where: M_{ij} = the mobility measure (capability) for the 1^{th} type unit performing the j^{th} mobility role

n_k = the number of the k^{th} type elements in the unit

$B_{ij}(n_k)$ = the total block time function for an i^{th} type unit comprised of n_k elements (k,1,2,...) to the place and time of choice while performing the j^{th} mobility role.

An enrichment of the measure which would reflect the firepower potential being delivered by the unit at the point of contact is:

$$\acute{M}_{ij} = \frac{\sum_k n_k \cdot \alpha_{k1}}{B_{ij}(n_k)} \qquad (2)$$

where α_{kl} is the rate at which systems in the k^{th} element can defeat enemy targets of the l^{th} type, its most likely target.* In words, the first mobility measure is the rate at which systems in the force are delivered to the place of choice, and the second measure is the rate at which potential combat power (as reflected by the ability to destroy targets) is delivered to the place of choice.

The block time $B_{ij}(n_k)$ is functionally dependent on n_k through the times to perform component activities of the j^{th} mobility role. Notationally, for the "move to point of contact" role,

$$B_{ij}(n_k) = f\ [\tau_d(n_k),\ \tau_c(n_k),\ \tau_o(n_k),\ \ldots\ \tau_i(n_k)\ldots\ ]$$

where: $\tau_i(n_k)$ = the times to perform the component activities such as deciding to move (τ_d), communicating the decision (τ_c), organizing the move (τ_o), moving (m), etc., each of which may be dependent on the number of K^{th} type elements, n_k ,

Recognizing that in most practical situations, the component activities would be performed both in parallel and serially (and accordingly might be analyzed as a network), if the times were completely serial, then

$$B_{ij}(n_k) = \tau_d(n_k) + \tau_c(n_k) + \tau_o(n_k) + \tau_m(n_k) + \ldots .$$

It is felt that the measures M_{ij} or M'_{ij} could be applied and calculated for any level of maneuver unit.

Two characteristics of the latter measure, M'_{ij} should be noted. For many missions α_{kl} is not the maximum rate at which enemy targets can be defeated, but the sustainable rate over some period of time. For missions that do not require the expenditure of more than

*Methods exist to predict the α_{kl} for all combinations of weapons and targets.

the basic load of ammunition carried by component elements of the force, this rate could approach the maximum rate of which the unit is capable. However, if a greater expenditure is required, the rate will drop to the rate at which ammunition can be resupplied. But the requirement to provide a continuing resupply of ammunition beyond the basic load imposes a significant additional load on the tonnage which must be carried and the resupply system that must be established. The same rationale applies to other support activities. Hence, the block time is significantly affected by the mission which the combined arms force should be ready to perform upon completion of the move.

A second consideration affects both of the measures propounded. Both involve block time and this is a very useful concept for visualizing the problem. However, the relationship of the various factors which one realizes intuitively must affect block time is not known. No predictive models for calculating block time exist although planning factors based on experience are shown in the field manuals.

5.3 TRADE-OFFS

5.3.1 One-on-One

The work group discussion of the relationship between mobility performance and other performance characteristics of a fighting vehicle centered principally on crew performance and capability as noted in paragraph 5.2.1, above. The implied requirement is for a strong human factors input to any analysis of the value of mobility. Trade-off discussions centered around a presentation entitled, "Modeling of Mobility and Armor Trade-off" by Dr. Masaitis of BRL (Annex B.4, Report of Proceedings) which links threat hit/kill probabilities (vehicle vulnerability/survivability) to mobility through vehicle weight (and therefore protection). The SAI literature review found that weight, expressed either as gross vehicle weight or horsepower/ton, was a popular parameter in mobility examinations. The results,

however, are not clear in that conflicting conclusions can be drawn with respect to heavy/slow, light/fast and heavy/fast vehicles depending upon one's point of view, methodology and certain technical inputs (e.g., special armor).

In sum, trade-offs are not well addressed per se, with the probable exception of the XM-1 "bands of performance"--and in this case, the gross vehicle weight limitation was a major parameter, which when coupled with vulnerability requirements drove the design solution. Here one should be reminded that the designer cannot sub-optimize everything. The potential for the trade-off of armor protection for mobility is certainly there, but is confused by the lack of a firm grasp of the survivability-mobility relationship, current test programs not withstanding.

5.3.2 Small Unit

The Tactical Mobility Work Group for Small Units deliberated on this issue and that work is considered below.

5.3.2.1 The Trade-off Between Movement Characteristics and Command and Control Characteristics

"More rapid deployment, therefore greater flexibility in choice and timing of missions."

The implication is that choice and timing of missions is movement characteristics limited. In general there are many other variables which dictate timing and limit choices at the small unit level. It has been stated elsewhere that development of taxonomies for other characteristics is a valuable step for trade-off analysis between characteristics. Such a taxonomy would undoubtedly show that the mission at the next higher headquarters would most likely regulate the timing although enhanced movement could permit its mission to be speeded up. But the choice and timing are equally if not more likely to be effected by communication, firing, intelligence, target acquisition and survivability characteristics.

"Permits command presence more expeditiously."

This is certainly true; but it is also related to communications.

"Greater flexibility in choice of defense positions and attack routes."

This is true and is related to the measures of performances discussed earlier for small units.

"More rapid displacement of command post."

The planning and reaction times involved in displacement of command posts is probably long in relation to movement times. This phenomenon is not entirely understood yet but is certainly a function of level. A platoon leader moving with his troops must be able to

"see" the battlefield and communicate down and up. As the level rises higher than company the need for intelligence, operations, and support control functions begin to drag the command control element. The solution requires a displacement by echelon and this imposes the added burden of maintaining knowledge of the state of the battle at two or more places. This in turn requires preparation and planning time and a "passing of command." Continuity of command is also relatively simple at platoon level and can be effected according to SOP in minutes. At higher echelons it requires alternate CPs (forward, main, rear) which add the burden of coordinating as the command level gets higher. It is conjectured that at the present state of movement technology that movement characteristics are not the limiting factor.

"Offers greater flexibility in altering force ratios by repositioning of forces."

This is a prime advantage of enhanced movement characteristics at the small unit level.

5.3.2.2 The Trade-off Between Movement Characteristics and Communications Characteristics

"Requires more rapid communication."

If this refers to processing at communications junction points (i.e., staffing and message processing) it is certainly true. The requirement for information exchange increases with level and is at the same time slowed by it. If more enhanced movement characteristics are now added to this situation a burden can in some tactical situations be added to the control of the unit vis-a-vis the feedback regarding the tactical situation. In turn, this requires a more rapid exchange of information. But at the small unit level it is then more a command and control problem than one of communicating. The quoted comment should be stated "Requires more rapid exchange of information."

"Allows greater flexibility in choice of communication sites. Power source can be on the vehicle rather than man portable."

This is true for OPs and CPs where gradability and traction are likely to pay off.

5.3.2.3 The Trade-off Between Movement Characteristics and Firepower Characteristics

"Direct fire. Higher mobility provides:

(1) More rapid movement between firing positions.

(2) Greater range of choice of firing positions."

Subparagraph (1) is more applicable to combat at the One-on-One level and is related both to survivability characteristics and firing characteristics. The tactical mobility literature reflects more maneuverable vehicles as being harder to track. Higher cross country speed exposes the vehicle less. Enhanced movement characteristics place more demands on suspension technology to enable vehicles to fire on the move. This can have the effect of enabling the increase of the rate of one-on-one fires. In turn this may place more demands on support systems for ammunition resupply. Subparagraph (2) can be of importance to small unit commanders in distributing one-on-one units.

"Indirect fire (mortars). Higher mobility provides:

(1) Greater rapidity of displacement."

There may be a trade-off here with range. Enchanced movement characteristics can support a more rapid movement of FEBA.

5.3.2.4 The Trade-off Between Movement Characteristics and Survivability

"Detectability - A more highly maneuverable vehicle <u>may</u> be more detectable when moving.

Pk hit - Highly mobile vehicle may be lightly armored. Therefore more vulnerable to hits though it may be less likely to be hit."

These are applicable to the One-on-One level. Much of the tactical mobility literature is concentrated on the issue of the trade-off of mobility-agility for increased survivability. Enhancing movement characteristics need not require lighter armor. The literature claims (Reference 13) that a great gain in the probability of survival occurs with increased horsepower per ton when the survivability probability is low. At 60 to 80 horsepower per ton the curve begins to flatten (Reference 16).

"Exposure time:

(1) Mobile vehicle may be larger (or smaller). Hence exposed a lesser or greater duration of time.

(2) More mobile vehicle moves from cover to cover more rapidly and so is not exposed as long per unit of travel."

Again this is more applicable to one-on-one level combat. Reference 4 (HELAST II) concluded that "Increased mobility/agility of target vehicles can significantly decrease the probabilities both of being detected and of being fired on" that "most rounds fired at tactical-type moving targets will be fired at targets which are only partially visible."

"Signature:

(1) (Referred to detectability-quoted earlier).

(2) Electromagnetic signatures may be different."

If the latter refers to target appearance on an MTI indicator the point is not a strong one; if it refers to infrared radiation some work is being done by the Germans (Reference 22) on enhanced engine exhausts to defeat thermal imaging sights. These items are also more applicable to One-on-One level combat.

5.3.2.5 The Trade-off Between Movement Characteristics and Human Factors

"Human Elements:

a. Mobility enhances the ability to quickly deploy forces."

Brain speed and communications delays may have more leverage on rapid deployment than current movement characteristics limits.

"b. More mobile vehicle requires a more highly skilled operator."

There is a human factors technology which is experimenting with suspension systems, sight stabilization and 360 degree view. (Reference 22.)

"c. Thinner ammo protection provides less crew safety."

An implicit assumption here is that enhancement of movement characteristics requires less armor protection. In the main it is probably true. This is part and parcel of the literature focus on increased survivability at some potential sacrifice of 'mobility/agility'.

"d. More rapid deployment results in less fatigue."

This can be very important to small unit commanders. It is also directly related to suspension engineering.

5.3.2.6 The Trade-off Between Movement Characteristics and Target Acquisition

"Target Acquisition:

a. Better selection of observation points.

b. Better capability to observe from a number of vantage points in a given time."

These are key to the small unit commander. It uses enhanced movement characteristics to offset the need for more battle feed-

back to offset the increased requirement for exchange of information cited for earlier. In effect it enhances battlefield presence.

5.3.2.7 The Trade-off Between Movement Characteristics and Service Support Characteristics

"Highly mobile vehicles: Require highly mobile (responsive) service support vehicles."

The exact meaning of this statement must be judged with care. Reference 5 (Mobility Technology Coordinating Paper) states in part: "...Combat Support Units Should Have Mobility Which Equates to That of the Units Which They Support...not intended to mean that combat support units have mobility that is fully equal to that of combat units...combat support units normally travel in friendly zones and have more selectivity...over maneuver areas..." Additionally Reference 32 (part of HIMO Study) states in part: "...As mission routes increased in distance the special mobility characteristics of the HIMO (high mobility) vehicles were less important to timely mission accomplishment. In fact, the HIMO vehicles were penalized by their comparatively slower on-road speeds..."

5.3.2.8 Other Factors

"Multiple Elements:

a. Increasing mobility of some vehicles in a unit may not increase the units' deployment speed if some vehicles are less mobile."

This implies that all vehicles must traverse the same terrain type and distance. Such a situation as above can be managed but it has an impact on the small unit commander's already heavy burdens. It can be included under command and control factors.

"b. Greater heterogeniety of mobility of elements in a unit could increase the command and control problem."

This comment is more of a caution flag for the materiel and combat developers and a very good reason for judicious planning than a trade-off issue.

The Small Unit work group also cited as a meaningful trade-off: "Trade-off force size for increased mobility for a fixed dollar cost..." An alternative (not necessarily contrary) viewpoint cited mobility as an implicit variable affecting force ratios. These concepts lead to the idea of mobility as a combat multiplier or more specifically mobility directly effects the ratio realized firepower divided by potential firepower. This ratio is a promising measure for evaluating the mobility/force size trade-off.[1]

5.3.2.9 Movement Characteristics Trade-off Relationships at Small Unit Level - Summary

The interrelationship of movement characteristics with other characteristics is summarized in Figure 5-5.

FACTOR	RELATIONSHIP THROUGH WHICH TRADE-OFFS CAN BE CONSIDERED
Command and Control	• Command Presence - Movement versus Communication • Potential Proliferation of Vehicles with Differing Movement Characteristics - Burdens Command and Control • Altering of Force Ratios - Force Sizing • Flexibility in Choice of Defensive Positions and Attack Routes - Firing Characteristics (Range) • Fatigue Potential of Troops - Force Sizing
Communications	• Less Mobility May Require Less Planning and Message Processing Time • Demand for More Rapid Exchange of Information - Enhances Battlefield Presence - Force Sizing • Flexibility in Siting Commo Elements - Force Sizing
Firepower	• $\left(\frac{\text{Realized Firepower}}{\text{Potential Firepower}}\right)$ Increases with Enhanced Movement Characteristics - Force Sizing • Less Mobility Requires More Range
Target Acquisition	• Requires More Feedback - Offset by Wider Selection of OP's and More Vantage Points Covered Per Unit Time

Figure 5-5. Relation of Enhanced Movement Characteristics with Other Characteristics - Trade-off Potential

[1]It is interesting to note that Tiede and Leake used this measure for evaluating the multiplicative effects of command control improvements. See Report RAC-R-100, INFORMATION FLOW AND COMBAT EFFECTIVENESS, Research Analysis Corp., June 1970.

5.3.3 Combined Arms Force

As has already been noted in paragraph 4.4, the existing taxonomy relating movement characteristics to missions provides a basis for assessing the possible trade-offs between movement characteristics, e.g., at the combined arms force echelon, the possible trade-offs between swim speed and other characteristics with significantly closer coupling, such as movement range, RAM-D, or road speed should be investigated. The taxonomy, without extension to cover performance characteristics other than movement, does not provide a basis for assessing the importance of trade-offs between mobility performance and other performance factors. However, as already stated in the foregoing discussion of performance measures for this echelon, block speed is a function of a number of performance characteristics in addition to road speed. The most important of these appear to be intelligence, firepower (sustained rate of defeating targets), and C^3.

5.4 MEASURES OF EFFECTIVENESS

5.4.1 One-on-One

The work group discussion of mobility measures of effectiveness resulted in one conclusion: MOE are not applicable to the one-on-one level and are better expressed as exchange ratios as a function of time for aggregated vehicles, i.e., small units. This conclusion, notwithstanding, the group agreed with the suggested "defeat" and "survive" missions, adding "observe" to accommodate reconnaissance vehicle missions. The literature review supports the group conclusion in that while much has been done with regard to "survivability," the interpretation of survivability in terms of mission accomplishment has not been clearly defined. In this sense the group conclusion is erroneous in that if "survive" is a valid one-on-one mission, MOE can in fact be developed for the one-on-one level, but their nature may require expression in terms of small unit effectiveness (e.g., exchange ratios as previously mentioned). See paragraph 5.7.5 for further discussion of such measurement.

5.4.2 Small Unit

The small unit work group agreed on the context for small units as battalions and lower. It was also a concensus that little was being done in analysis and testing beyond measuring casualties and exchange ratios. A suggested goal for measuring success at small unit level was the probability of mission success as a function of mobility level. It was agreed that there are measurable elements which contribute to this. Small unit mission accomplishment can be measured in terms of three parameters: Displacement in the presence of a red force (area taken, area denied), resources (required and expended--both red and blue), and time. It was believed that probability of mission success can be measured in these terms. Examples are shown in Figure 5-6.

MISSION	DISPLACEMENT	RESOURCES	TIME
ATTACK TO SEIZE OBJECTIVE	SPECIFIED	MINIMIZE	SPECIFIED
HASTY DEFENSE OR DELAY	MINIMIZE	NOT MORE THAN SPECIFIED LEVEL EXPENDED	SPECIFIED OR MAXIMIZE
DEFEND AT ALL COSTS	SPECIFIED	MINIMIZE	SPECIFIED
EXPLOITATION	MAXIMIZE	NOT MORE THAN SPECIFIED LEVEL EXPENDED	MINIMIZE

Figure 5-6. Measurable Small Unit Mission Parameters

An appropriate portion from the work group report is quoted. "The initial deployment of and planned activities (including contingency actions) of each unit within the Blue battalion and the Red force must now be prepared. The model must incorporate all activities of participating battalion units. In this case [Delay] success might be defined as getting to the fall-back position with 90+% of

the company (less than 10% casualties) and having stayed at the initial position until Red was at 1000 M. Failure might be defined as 80% Blue casualties and partial success may be defined as an inverse linear function of Blue casualties between 80% and 10% of Blue casualties. Model output should be: P (Success); Red and Blue killer-victim scoreboard; elapsed time; etc. The sensitivity of these results to a variety of terrains and mobility levels must be examined. Altered tactics must be allowed for if mobility changes will permit their use.

A small but representative spectrum of scenarios exhibiting battalion missions, including subunit missions, must be prepared in which time and/or motion are of the essence. Also, a small but representative selection of terrain must be selected which depict the spectrum of terrain on which a battalion will conduct operations. An importance factor of frequency of occurance of each mission and terrain must be prepared. A model to do all of the above needs to be developed. It is essential that it be capable of incorporating all of the activities of participating units of the battalion, including the contingency activities."

The measure of effectiveness 'probability of success' is certainly a desirable goal. Extending the impact of movement characteristics to mission outcome in terms of measurable quantities is a required one. The important work to be done is to gain the ability to classify mission accomplishment in terms of measurable quantities with appropriate thresholds and be able to compare or rank outcomes as movement characteristics are varied.

5.4.3 Combined Arms Force

No special measures of effectiveness for assessing the pay-off from a unit's tactical mobility in the context of a combined arms engagement are needed. Such engagements involve the interaction of all of the military functions, e.g., firepower, intelligence, C^3, mobility, service support, simultaneously and their outcomes in terms of relative resource expenditures (casualties), FEBA movement and time provide an adequate basis for measuring force effectiveness. Such outcomes are usually generated by means of simulated engagements. Such outputs must be combined into a single measure of effectiveness. One means for doing this was suggested by the Combined Arms Force Working Group who suggested that a useful measure was:

> "The percentage of the actual size threat force opposing the combined arms unit that it can defeat."

Such a definition requires the establishment of defeat criteria and multiple trials to determine just how large a force can be "defeated."

A variation of the above measure overcomes some of the semantic difficulties associated with the word "defeat" (e.g., some missions may require avoidance of contact with the main body of the enemy). The alternative measure is:

> "The largest fraction of the actual size threat force opposing the combined arms force that it can face and accomplish its mission."

Such a definition of the effectiveness measure also eases the problem of establishing defeat criteria since, as has been shown by Tiede,* the military mission can be transformed into a set of constraints in area, resources, and time.

5.5 QUANTIFICATION MEANS

5.5.1 One-on-One

In view of the conclusion recorded in paragraph 5.4.1 (MOE are not applicable at the one-on-one level), the work group did not address the adequacy of analytical quantification means. The literature review did, however, record means by which mobility performance can be linked to small unit effectiveness, principally in the IUA/Bonder/AMSWAG type models and resulting exchange ratio calculations (providing these are in turn linked to mission accomplishment).

*Tiede, R. V., "A Formulation of Ground Combat Missions in Mathematical Programming Form," Research Analysis Corp., Technical Paper RAC-TP-265, July 1967.

5.5.2 Small Unit

In the measure of effectiveness discussion for small units (Section 5.4.2) a proposal was made for a model to be developed to measure probability of mission success in terms of measurable mission performance factors (displacement, resources, time). It was further stated that it be sensitive to terrain and incorporate all activities of participating battalion units to include contingency activities.

Later in the deliberations it was stated as a work group position that it is more effective to build on the current model and simulation base rather than construct new models. It was pointed out that TRADOC has initiated a model improvement program. Current model deficiencies that impact on the measurement of the value of tactical mobility were listed as follows:

- Portrayal of a smoke environment
- Representation of the phenomenon of suppression
- Representation of minefield negotiation
- Impact of logistical mobility
- Portrayal of day versus night operations
- Representation of facets other than those of combat.

The current models are not at the same time sensitive to all movement characteristics and combat outcome at the small unit level. It may take a hierarchical approach to accomplish those sensitivities. It is probably more cost effective to build on the current model base rather than develop wholely new models. A beginning approach might be to conduct a review of those models used in the XM-1 COEA, investigate the minimum requirement to best include all movement characteristics and then investigate how the features listed above can be incorporated. It would appear that this could best be done in conjunction with

TRADOC's model review. But it may need centralized Army direction to maintain the momentum of focus.

5.5.3 Combined Arms Force

Quantifying the combat effectiveness measure defined in paragraph 5.4.3 above requires use of an appropriate combat model, i.e., war game, computer simulation, etc. The Combined Arms Force Working Group found that a number of such analytic tools exist at different levels of resolution. They stated:

"The first set would permit relatively detailed assessment of the effects that "block time" and "components" of the block time have on combat effectiveness. These include the DIVWAG* war game and the VECTOR-2 simulation.** DIVWAG could provide assessments of division level campaigns and VECTOR-2 of corps and theater campaigns. Although DIVWAG is a war game, a sufficiently large number of previous analyses have been conducted with it that these results could be used to conduct a number of appropriate mobility analyses rapidly. VECTOR-2 requires approximately 8 seconds/sector***/day of CPU time on the AMDAHL 460V/6 computer. (A 30 day, 9 sector campaign was run in less than 40 minutes of CPU time.) Either of these analysis tools could conceptually generate curves of the type shown in Figure 5-7.

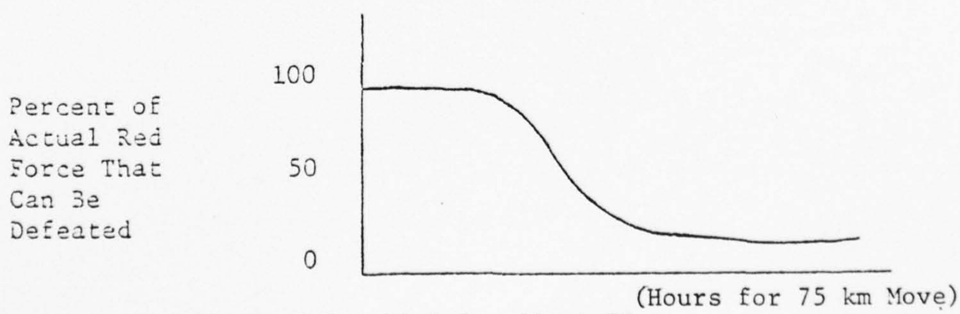

Figure 5-7. Division Block Time

*US CA CENTER CACDA, "DIVWAG Model Documentation," Technical Report 8-76, July 1976, 3 volumes.
**George Miller (ed.), The VECTOR-2 Theater-Level Combat Model. Vol. I: Users' Manual, Report Number VRI WSEG-4, 5 FR77-1 (R), Vector Research, Inc., 28 February 1977.
***A sector models approximately a 1-2 corps sized campaign.

Similar curves could be generated for each of the component activity times.

A set of more aggregated simulations exist that <u>might</u> be used to examine the effect of the "total block time" on combat effectiveness, but do not have the capability to examine the impact of the mobility component times. These models include IDAGAM, VECTOR-1, CEM-IV, and LULEJIAN."

5.6 MEASUREMENTS OF TACTICAL MOBILITY EFFECTIVENESS

5.6.1 <u>One-on-One</u>

The one-on-one work group did not address the measurement of MOEs with respect to individual vehicles. While test descriptions presented in the work group report (p. 147, Report of Proceedings) purport to do so, these tests in reality address measures of performance.

The literature search discovered one-on-one measurement (quantification) coverage for the following links at the frequencies (number of extracts) noted:

Link			Quantification Technique			
Characteristics	Function	Mission	Testing	Modeling	Analytic	Total
Acceleration	Evade	Survive	5	4	3	12
CC Speed	Move UGO*	Defeat	4	4	2	10
CC Speed	Move UGO	Survive	3	4	3	10
Traction	Evade	Survive	2	0	3	5
Traction	Move UGO	Defeat	3	1	0	4
Traction	Move UGO	Survive	3	1	1	5
Turning Radius	Evade	Survive	3	1	2	6
			23	15	14	52

Despite the small sample size, the numbers indicate the dominance of testing over modeling and analytic techniques as well as acceleration and cross country speed over traction and turning radius (as well as

*Move under ground observation

other characteristics for which no quantification effort was noted.) Interestingly, cross country speed and traction were listed as items 1 and 2 in terms of relative value to the combined arms force in terms of its mission performance, while acceleration was listed (in a tie) for 6th place (see Figure 3-15, page 3-29). The testing orientation towards acceleration/cross country speed-survive is also borne out in Appendix C. One can, however, ask if we are not testing before we understand the problem? See also the discussion at paragraph 5.7.5, page 5-35.

5.6.2 Small Unit

Section 4 and Appendix F of this report provide an analysis of what has been done to measure the effectiveness of tactical mobility based on a contemporary literature sample. In the area of small unit combat, it was found that in general simulations, gaming and analysis had been done at the small unit level but that results in terms of small unit mission performance was rare and that not all movement characteristics were being portrayed. Movement characteristics which provide direct links to small unit mission accomplishment are gradability, cross country speed, road speed and traction. In terms of potential mission influences, cross country speed and traction were rated the highest; i.e., most likely candidates to influence mission accomplishment of small unit level. The contemporary literature generally fell short in establishing a link to mission performance generally because it wasn't shown whether the mobility differential made a difference in a small unit seizing or denying seizure of an objective. What has been done in this area is spotty for the small unit level. The usual measures for studies at the small unit level is exchange ratios, attrition rates, etc. When such resource consumption rates are accepted as the sole measure of combat effectiveness, a favorable exchange ratio implies success whether or not the unit mission is accomplished. Some missions may require high

rates of attrition (e.g., defend at all costs). Analysis must include mission considerations as a necessary condition. Resource consumption alone is not sufficient.

5.6.3 Combined Arms Force

The Combined Arms Force Working Group confirmed the finding of the literature search that little has been done to measure the impact of changes in tactical mobility on the effectiveness of the combined arms force. This had been a stated EEA for the ACCB III/TRICAP II testing, but these tests were cancelled. Several of the heavy division organizational ideas being investigated by TRADOC in its ongoing Division Restructuring Evaluation relate directly, to wit; the following assertions will be investigated in both field tests and war gaming supported analyses:

> "Control of the combined arms battle at the battalion task force versus the company team level will have a positive effect upon a division's tactical mobility."

> "Maneuver unit composition of fifteen* smaller maneuver battalions versus the current structure of eleven larger battalions will increase the division's tactical mobility."

> "Reorganization of the division's aviation assets under more centralized control will increase the tactical mobility of these assets through increasing 'mission' responsiveness."

5.7 DATA, TESTING, ANALYSIS GAPS

In the Tactical Mobility Working Meeting each work group addressed the question: "What are the data, testing and analysis gaps?" at the one-on-one, small unit and combined arms force levels. Their deliberations are summarized in Figure 5-8.

The gaps highlighted by the working groups can be summarized as follows:

5.7.1 One-on-One

Gaps a through d (Figure 5-8) relate to human factor interaction with mobility. Gaps e through g relate to mobility's interaction with survivability. Implicit in these relationships is trade-off potential. The point has been made elsewhere (Section 4) that these relationships as well as other factors need to be defined and that a basis for doing so would be to extend the taxonomy. In Section 4 it was found that the effect of braking on one-on-one missions was neglected. The impact of traction and turning radius was slighted.

5.7.2 Small Unit

The small unit work group found many gaps that relate to the impact of movement characteristics on unit mission performance. These are shown at 2.d through 2.i of Figure 5-8. Of the remainder, the following relate to potential trade-offs with the other factors shown below.

- b - Command and Control, Communications
- c - Command and Control
- j - Survivability
- k - Survivability
- l - Target Acquisition
- m - Survivability
- n - Target Acquisition
- o - Survivability
- p - Command and Control.

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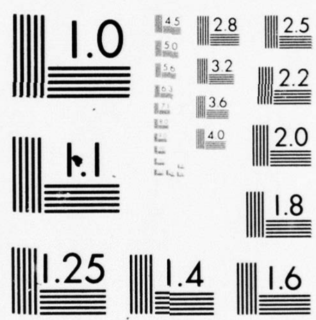


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

LEVEL	GAPS	DATA	TESTING	ANALYSIS	JUDGMENT	NOT STATED
1. One-on-One	a. Improved Mobility Influence on Crew Task Performance					X
	b. How Much Mobility is Crew Usable?					X
	c. Impact on Improved Vehicular Mobility on Small Unit Mobility					X
	d. Limits to Combat Vehicle Mobility in a Tactical Situation					X
	e. Effect of Armor Protection on Mobility					X
	f. Effect of Improved Mobility on Target Exposure					X
	g. Effect of Vehicular Performance (g Level) on Evasiveness					X
2. Small Unit	a. Time to Execute Maneuver as Function of Mobility System(s)	X	X	X		
	b. Constraint of C^3 on Realization of Vehicle Mobility-Tightness of Command	X	X	X		
	c. Control of Subunit Exposure by Commander		X			
	d. Casualties of Over Watch Elements of a Function of Maneuver Elements			X		
	e. Differential Mobility Required to Perform Mission	X		X	X	
	f. Unit Maneuver Rate as a Function of Mobility Differences Within Unit and Effects of Tac Air	X	X	X		
	g. Frequency of Unit Success as a Function of Route Selection	X		X		
	h. Firepower Repositioning Time Impact or Resulting Battle Outcomes	X	X	X		
	i. Engagement Outcome as a Function of Tactics Made Possible by Mobility	PRI*	PRI	PRI	PRI	
	j. Frequency of Unit Detection and Identification	X	X			
	k. Decrease in Unit Detection and Identification as a Function of Route Selection Flexibility	X		X		
	l. Frequency of Success in Reconnaissance as a Function of Unit Mobility	X		X	X	
	m. Extension of STAGS Data to a M-on-N Situation	X	X			
	n. Estimates of Probability of Target Acquisition While Moving	PRI	PRI			
	o. Exploitation of Mobility on Unfamiliar or Hidden Threat (e.g., Minefields) Terrain	PRI				
	p. Trade-off Between Using Mobility Potential and Maintaining Small Unit Cohesiveness	PRI				
3. Combined Arms Force Level	a. Effects of RAM Increases in Major Combat Systems					X
	b. Effects of Shortening the Planning and C^3 Processes Associated with Maneuver Unit Actions/Reactions					X
	c. Effect of Providing More Timely Intelligence at the Corps, Division and Brigade Levels					X
	d. Elements of Block Time--Definition and Value--Taking Advantage of Exercises Such as REFORGER	PRI		X		
	e. Vulnerability of Surveillance Radars Near the FEBA and How Mobility Can Offset			X		
	f. Contribution (To Reducing Block Time) of Combat Engineers in Clearing and Establishing Routes--Both Unopposed Movement and Movement Under Fire			X		
	g. Logistics	X	X			
	h. Administrative	X				

*Priority.

Figure 5-8. Summary of Tactical Mobility Working Meeting Deliberation on Data, Testing and Analysis Gaps

The comment for the one-on-one level is applicable here: A basis for defining these relationships could be establish could be established by extending the taxonomy.

5.7.3 Combined Arms Force

During the mobility working meeting the comment was made that in a short war scenario improvement of RAM-D would not produce an effect because of high combat loss rates. The fact is that this movement characteristic and its impact on mission accomplishment has been largely neglected. This was noted (gap a) by the combined arms force work group. Gap f relates movement characteristics to combined arms mission performance. The other gaps identified by the work group involve potential trade-offs with other factors that can also effect mission performance follows:

- b - Command and Control, Communications, Intelligence, Human Factors
- c - Intelligence, Human Factors, Communications
- e - Survivability, Target Acquisition
- f - Combat Support
- h - Service Support

Gap d introduces the concept of block time (discussed elsewhere) which can impact heavily on mobility decisions and relates to many of the factors which need to be included in an extension of the taxonomy.

5.7.4 Summary of Work Group Gaps

Two types of testing analysis and data gaps were exposed by the mobility meeting work groups: Those that related mobility performance to combat mission performance and those with implicit interaction with other factors also contributing to mission performance. In addition, the force level work group introduced the concept of block time. Table 5-3 summarizes the classification of gaps highlighted into the above types and relates to Figure 5-8.

Table 5-3

GAPS IDENTIFIED BY TACTICAL MOBILITY WORKING MEETING WORK GROUPS

FACTOR	ONE-ON-ONE	SMALL UNIT	COMBINED ARMS FORCE
MISSION EFFECTIVENESS		2a,2d,2e,2f,2g,2h,2i	3a,3f
COMMAND AND CONTROL		2b,2c,2p	3b
COMMUNICATION		2b	3b,3c
FIRING			
SURVIVABILITY	1e,1f,1g	2j,2k,2m,2o	3c
HUMAN FACTORS	1a,1b,1c,1d		3b,3c
INTELLIGENCE			3b,3c
TARGET ACQUISITION		2l,2n	3e
SUPPORT			3g,h
TRAINING			
DOCTRINE			
BLOCK SPEED			3a,3b,3d

5.7.5 Other Gaps

Table 5-3 is suggestive that there are other gaps in relating mobility to combat mission performance. During the mobility working meeting it was suggested that a moratorium in testing may be beneficial while the existing test data is reviewed and correlated. It is not recommended that such a moratorium be declared. The lead time required to set up field testing is long enough during periods of active testing. Stopping the momentum of the testing community while reviewing the data base may have a deleterious effect when the need is felt to begin active testing again and we find ourselves at the low point on the learning curve. A prudent program would seem to be to expand the taxonomy to include other factors; then apply it to the existing data base as a basis for correlation. There is no reason that this cannot be done while testing is in progress and such a scheme may mutually benefit testing and gap filling.

In reviewing the "collection" of tests described in Appendix C, one is led to the conclusion that, with the exception of the ACVTP, the general approach has been to address individual problems or questions on an individual basis rather than as a part of an overall problem area. This approach has probably resulted from questions being raised sequentially, rather than in parallel, and the scheduling of tests in the same manner (e.g., when the pressing question of the day is "How good are ATGM?", one immediately schedules an ATGM test; when the next concern is "What about gun fire control systems?", one schedules another test to look at fire control). While the discrete approach is correct in terms of the design of individual tests, the potential for aggregating and correlating results and conclusions is far less than if a coherent test program existed within the framework of which test design could proceed. This discussion is certainly not intended to imply that good work has not been done, but rather to emphasize the requirement for a program approach to the problem of tactical mobility, its impact on weapon systems, and its contribution to effectiveness.

One can certainly visualize a theoretical test program which proceeds from the one-on-one level to the small unit and then to the combined arms force. However, combat vehicles do not operate individually on the battlefield for other than short periods of time. One of their major constraints is the tactical movement requirement(s) of the small unit (as a minimum, the old adage about "always employ tanks in pairs" applies). This suggests an approach to program design which starts with the examination of small units in a free maneuver context and the cataloging of one-on-one situations taking place within that context. It is these situations which then must be further examined in one-on-one tests so that the results can then be aggregated upward in terms of contributions to small unit effectiveness. A start in this direction is the work done at Fort Knox in determining the actions, activities and requirements for the armored cavalry platoon (References 54,55, and 56).

5.8 PRIORITIES FOR FUTURE ACTIONS

This section will address key actions that need to be taken at each level to resolve issues, gaps and debilitating findings. They will first be covered by level and then summarized in the order in which the actions need to be taken. The actions summarized are all high priority. Their salutory friction is a time sensitive one. Therefore their ordering is not according to importance but rather according steps for accomplishment.

5.8.1 One-on-One

At the small unit level the key gap is an apparent conflict in the literature regarding the trade-off of mobility/agility for increased armament to gain survivability. This issue has been looked at in the context of One-on-One level combat. Two criticisms are leveled at the current approach. First the analysis is producing conflicting results. Some references add armament and find survivability decreasing, others find survivability increasing. Second, the context has been limited to the one-on-one level not only for movement characteristics but also for survivability and human factors. There may be other factors which can affect combat outcome that are involved. Probably the higher levels can be dealt with parametrically for indirect movement characteristics, but it must be realized that if movement characteristics are degraded to buy heavier armor protection, there are direct effects at small unit and combined arms force levels. Likewise in an expanded taxonomy, survivability and human factors may also have direct effects at higher levels. This issue certainly needs to be resolved but is dependent upon an expanded taxonomy.

5.8.2 Small Unit

At the one-on-one level mission success can be and generally is represented by relative resource consumption between the two opponents. At the small unit level two other dimensions are necessary

before impact of changing movement characteristics on mission performance can be measured. These are area exchanged and time for mission accomplishment. Current small unit analyses are generally neglecting the latter two. (As pointed out before, a notable exception is the XM-1 COEA.) Additionally, current modeling purports to change mobility at small unit level by changing cross country speed only. Although it is not always clear what movement characteristics are involved when authors use the term mobility. In any case current models are not sensitive to other movement characteristics at the small unit level and particularly traction which was rated as having high potential impact on small unit mission accomplishment. The impact of other characteristics needs to be verified. A new modeling effort is probably not needed to sensitize analyses to dimensions other than relative resource consumption and to movement characteristics other than speed. A model improvement program should suffice and could piggy-back on the current TRADOC model improvement program. Centralized Army direction over the long term may be advisable. Trade-off analysis at the small unit level suffers from lack of a unifying structure relating factors,including movement characteristics, which can affect combat outcome.

5.8.3 Combined Arms Force

The literature search revealed and the Tactical Mobility Working Meeting confirmed that not much analysis and testing has been performed to assess (or predict) the contribution that tactical mobility of a combined arms force makes to the force combat effectiveness. The Combined Arms Force Working Group identified three classes of activities that might be performed to better understand (and thus predict for cost effectiveness or trade-offs) the combat pay-off of tactical mobility.

- "Reverse" analysis to determine the changes in force effectiveness resulting from parametric changes in force mobility, i.e., in the block times and associated components of block time (paragraph 5.2.3). Such an effort could be carried out using one or more of the quantification tools (models) cited in paragraph 5.5.3. The purpose of such an effort would be to provide some understanding of the first order effects of force mobility and to determine measurement accuracy requirements for prospective mobility oriented experiments.

- Design and conduct of tactical mobility experiments to measure the force mobility capability (block time and its components) for different forces under varying mobility modes under different scenarios (missions). Such data would provide a basis for:

    - Assessing the current mobility capabilities of forces.

    - Developing input data for use in analytic studies of the contribution of mobility to combat effectiveness.

- Develop input data to structure the block time function and develop predictive models for the component times in the block time function.

- Develop predictive models of the block time function and its components as defined at paragraph 5.2.3.

Clearly, an attempt to embark on all three activities simultaneously would be prohibitively expensive and difficult to justify. One needs, therefore, to look at which of these proposed activities is most urgent and which would make the largest immediate contribution to the basic problem of quantifying the value of tactical mobility. The first activity, parametric analysis of the effects of changing tactical mobility, is basically a sensitivity analysis. The mobility portion of current combat models at this level is based on current military procedures for movement planning and on the planning factors in use. Thus, the mobility factors are really highly aggregated inputs to the model. That combat effectiveness is significantly improved through major improvements in mobility, i.e., reduction in block time, is intuitively quite obvious. As expressed by the working group chairman, Wilbur Payne*, "Collectively, we thought that was so obvious in that characteristic kind of situation, like the movement of significant fractions of the U.S. force from CENTAG to NORTHAG in short warning situations, that if a model didn't tell us it was important, we would keep fixing the models until they did." In fact, combined arms force improvement as a result of changing block time has already been demonstrated by Tiede and Leake.** In that case, reductions in block time were accomplished by changes in command control communications performance, but that has already been postulated to be a major component of block time.

*TACTICAL MOBILITY WORKING MEETING, 26-27 July 1977, SAI, August 1977, page 268.

**R. V. Tiede and L. A. Leake, "A Method for Evaluating the Combat Effectiveness of a Tactical Information System in a Field Army," Opns. Res. 19, 587-604 (1971).

On the other hand a major program of testing and experimentation to measure force mobility capability in terms of block times and its components cannot profitably be undertaken until we have a better understanding of the processes that contribute to block time delays and their interrelationships. Until that has been accomplished, some useful mobility data can undoubtedly be collected by observing or piggy-backing on already planned field exercise such as REFORGER or TCATA tests. A major data collection effort should, however, await a better understanding of the phenomenon, or at least an hypothesis as to its nature.

This leaves the third activity which we believe to be fundamental to gaining a better understanding of the value of tactical mobility at the combined arms level. Network analysis is undoubtedly applicable to the sequence of processes and activities required to make and execute the decision to move a combined arms unit from Point A to Point B in a posture to undertake a specified mission. As was pointed out by the working group, this total time is very large, as much as 20 to 50 times the time for a single vehicle to move that distance. Nevertheless, there may be situations in which vehicle movement time is on the critical path, as was demonstrated in the simple example at paragraph E.2, Appendix E.

5.8.4 Priority Actions - Time Sequenced

5.8.4.1

A relational structure or taxonomy needs to be developed which considers characteristics of those factors which can impact on tactical mission accomplishment at all levels. A prudent way of doing this is simply expand the tactical mobility taxonomy within which combat missions and functions are already related. Other factors to be considered are command and control, communication, firing, survivability, human factors, intelligence, target acquisition, support, training and doctrine. Such a structure needs to be kept up to date and can form a basis for trade-off analysis, correlation of data bases, structuring tests and analyses and reviewing model coverage.

5.8.4.2

Apply the extended taxonomy to correlate existing testing and other original source data bases. Current tests and test programs should not be curtailed while this is ongoing. Curtailing would not only deny potential cross benefit, but is probably not cost effective in view of the long lead times required for cranking up a testing program. Field tests should not be overlooked in this process. The testing of the restructured division at Fort Hood and exercises such as CHINESE EYE III and REFORGER should be plumbed for data and their correlation with other data. The output of this effort should be a report which covers new findings and remaining gaps. Hopefully, some gaps can be closed by this effort.

5.8.4.3

Apply the expanded taxonomy to trade-off analysis. This should be done with two goals in mind. First to resolve the current apparent conflicts in the trade-off of mobility/agility for increased armament to gain survivability. This would imply a centrally directed study to consider the applicable portions of an expanded taxonomy. Second, use the taxonomy to discover potentially new trade-offs. On the basis of this research specific trade-off analyses can be directed. This second application of the taxonomy should be a centrally directed research effort.

5.8.4.4

Improve existing models to increase sensitivity above the one-on-one level to movement characteristics other than speed and to increase sensitivity to dimensions of combat outcome other than relative resource consumption. Specific movement characteristics which must be included are gradability at the one-on-one level; traction and cross country speed at small unit level, and movement range and RAM-D at combined arms force level. Specific dimensions of combat outcome other than relative resource concumption are area exchange

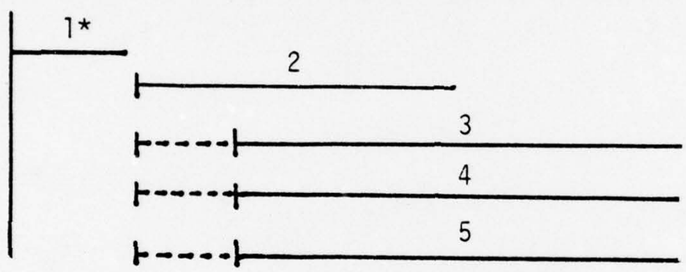
(or control) and time. This effort can be satellited on on-going model improvement programs.

5.8.4.5

Initiate a block speed modeling effort. In its initial phases this program should search for an understanding of block speed; its components together with their interactions. This should be a directed research effort.

5.8.4.6

The relative time sequencing is shown in Figure 5-9.



*1. Expand Taxonomy
2. Apply Expanded Taxonomy to Data Base
3. Apply Expanded Taxonomy to Trade-off Analyses
4. Improve Existing Models
5. Block Speed Modeling in 3, 4, and 5.

Figure 5-9. Time Sequencing

The dashed lines indicate that a low level of effort could begin after expansion of the taxonomy, but that the completion of the efforts may be dependent or changed by what will be found in the data base.

Section 6

FINDINGS

- The contributions of technology and engineering to tactical mobility have been and are continuing to be well examined and documented; the contribution of tactical mobility to combat effectiveness is not.

- For the past few years, mobility investigations have been dominated by one-on-one survivability and hardware performance considerations. The thrust of both the U.S. Armored Combat Vehicle Test Program (ACVTP) and FRG programs continues in this direction.

- Investigations of combined firepower and mobility systems tend to concentrate on the effects of changes in firepower performance with much less emphasis on the effects of changes in mobility performance.

- The Army does not appear to have a structural basis for trade-off analysis among factors which contribute to combat mission success, e.g., between mobility and firepower, C^3, intelligence, support and many more. Among these, human factors, to include control of maneuvering vehicles and units, seem to have been submerged in the survivability investigations.

- There is conflict in the literature regarding the trade-off of armor protection for movement performance; some analyses are showing an increase in survivability, others a decrease.

- The taxonomy developed in this study appears to provide an adequate basis for structuring the relationship between mobility and combat effectiveness and for assessing the potential value of trade-offs between movement characteristics at the various echelons and even between echelons. A program to expand the mobility

taxonomy to include other factors contributing to mission success appears fruitful in terms of discovering gaps in areas other than mobility, correlating the Army's data base, structuring the testing and analysis programs, and investigating trade-offs.

- The application of such an expanded classification system, structured in terms of Army ground force mission accomplishment, to the testing data base and other source data bases would be fruitful as a means for correlating existing information and help to close tactical mobility and other gaps.
- The tactical mobility literature has neglected the impact of movement characteristics on tactical mission accomplishment above the one-on-one level. Much of this relates to a lack of understanding of the notion of block speed and the current inability to relate all tactical vehicle movement characteristics to combat outcomes at all echelons, especially above one-on-one level.
- The truism that increased range is substitutable for mobility in certain support functions (e.g., artillery, ground radar) must be carefully examined. The nonlinearity of this trade-off relationship may make this assertion valid only over a limited domain.
- The fundamental gap in quantifying the value of tactical mobility is the lack of a predictive model for determining the total time (from causative event to completion) required to move a combat force in order to carry out a military mission.
- There is a need to expand model scenario coverage beyond the normal "attack" (and to a lesser degree "defend") to such missions as "exploit," "delay" and "pursue".

Section 7

RECOMMENDATIONS

It is recommended that:

- The mobility taxonomy be expanded to include other factors that impact on combat mission outcome at all levels.
- The expanded taxonomy be applied to the testing data base and other original source data bases (to include field tests and unit exercises) to correlate data and close mobility and other gaps.
- The expanded taxonomy be applied to guide resolution of the mobility/agility versus survivability issue and to discover other areas for beneficial trade-off research.
- Existing models be improved to sensitize their combat outcomes to movement characteristics impacting on tactical mission performance in addition to relative resource consumption. This effort should encompass a wider range of scenarios than heretofore addressed and be conducted in consonance with or as a part of the TRADOC model improvement program.
- A "block speed" modeling effort be initiated.
- The Army/DARPA ACVTP program be continually reviewed to ensure that tactical mobility considerations are not dominated by hardware technology and pure one-on-one survivability testing.
- Design of small unit free maneuver testing program be initiated with the objective of examining one-on-one results in a broader context.

Note: The sequence for executing these recommendations is shown in the chart in paragraph 5.8.4.6.

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Appendix A

DIGEST OF LITERATURE EXTRACTS BY KIND OF INFORMATION

TABLE OF CONTENTS

Appendix A

DIGEST OF LITERATURE EXTRACTS BY KIND OF INFORMATION*

A.1 PERFORMANCE MEASURES

1. "...the chance of tank survival increases between what is apparent to the gunner and what is real. To relate the difference between these two factors to the probability of survival, it is necessary to determine what is apparent and what is real... Table I Error terms and definitions. Line of vehicle position X minus line of aim equals aim error L. Target speed $\dot{x}$ minus tracking rate $\dot{\gamma}$ equals tracking error R. Apparent target acceleration $\ddot{x}$ minus apparent gun acceleration $\ddot{\gamma}$ equals rate of change of tracking error R."

2, p 320

2. "This analysis coupled with field test data leads to an interesting observation. The influence of mobility and agility of the tank on the increase of survival probability can be characterized by the standard deviation of the apparent acceleration."

2, p 321

3. "The FVT-02 had...arrangements whereby the tank commander could turn around in his station in order to drive the tank backwards. The commander and gunner were provided with a system of rotating mirrors which provided them with uninterrupted 360-degree vision when buttoned up...an electric drive as a secondary power source...for use in the 'silent watch' mode, for short movements requiring maximum stealth, and for emergency use should the main engine fail."

22, p 2

4. "Possible qualitative effects of obstacles are cited from several sources... In the meantime, the usual measures seem less like MOE (measures of effectiveness) and more like MOIE (measures of incidental effects.)"

23, p v

5. "In order to quantify target motion relative to the firer, it is hypothesized that the following parameters characterized this motion: 1. Apparent acceleration, 2. Apparent velocity, and 3. Rate of change of target aspect relative to the firer."

24, p 2

6. "...operational mobility is particularly concerned with... performance...on hard, level surfaces... primarily a function of... power-to-weight ratio. Ability to move over broken ground...primarily a function of vehicle dimensions, particularly length, at close to zero speed and of length and suspension design as well as power to

*Each of the items selected for analysis is quoted in part and is followed by a number keyed to the references and page number where appropriate. Circled reference numbers belong to Class 1--contributory to linkages (complete or partial). Noncircled reference numbers belong to Class 2--noncontributory but useful background or data.

weight ratio at other speeds. Ability to move over soft terrain... given adequate power...a function of the ratio of vehicle weight to its ground imprint...generally deteriorates as vehicle weight increases. Ability to cross water obstacles...primarily a function of weight... Operating range or endurance...governs the frequency of halts enforced by the need to refuel...a function of fuel tank capacity and power plant efficiency...dictates the degree of logistic support...a function of their weight. Reliability and maintenance requirements...govern the availability...in time...primarily a function of the complexity of vehicle design and...weight."

30, p 7, 8

6. "Speed is usually limited by either the propulsion system of the tank or the tolerance of the crew to vibration levels. In some instances, speed may also be limited by factors such as poor visibility or the necessity to maneuver around obstacles. The maximum speed of the tank is a function of the grade and soil type, while ride limitations vary with the roughness of the terrain... In addition to velocity, a tank's mobility may be limited by its endurance or road range between refuelings..."

35, p 9, 10

7. "The general analysis data on comparative mobility of competing weapons is output...in terms of the percent of a given land mass which can be negotiated on a cross-country basis, according to speeds which the vehicle under consideration can achieve.

" The speed area index (SAI) is designed to give equal weight to the speed achieved by a vehicle and the percentage of area which can be traversed at those speeds."

52, p 5-5, 5-6

8. "The concept of the availability of tanks in time and space is more meaningful than that of 'mobility', which is usually invoked in this context and which is either too vague to be of use or is narrowly interpreted in terms of parameters such as road speed. In essence...it amounts to the probability that the tank will cover a specified distance in a given time."

57, p 141

9. "The simplest sequence into which the achievement of success against a hostile tank may be broken consists of three consecutive events. The first is arriving in time within striking distance of the target. The second is surviving to engage the target. The third is inflicting lethal damage by engaging the target."

57, p 133

10. "Formula for Measuring Defense and Retrograde Mobility...
$M_D = S_R \times K_2\ (1 - D_{TW})$ where:

(a) M_D = Mobility in defense/retrograde

(b) S_R = Unopposed relative speed

(c) K_2 = Mobility factor for defense/retrograde

(d) $1 - P_{TN}$ = Movement capability as a result of terrain weather... K_2 is a decimal between 0 and 1. It describes the defender's residual mobility...

...the mobility of an attacking unit can be expressed by the following formula:

$M_k = S_R\ (1-D_F)(1-D_{TW})$ where M_A = mobility of attacker, S_R = Unopposed relative speed of a unit D_F = Degradation to mobility as a result of enemy firepower, D_{TW} = Degradation to unit mobility as a result of terrain and weather."

1, p A-16

A.2 EFFECTIVENESS MEASURES

1. "...I was contacted by Mr. Richard Tuck, GAO, who informed me that he was working on a report to Senator Eagleton concerning the XM1 program. Specifically, Senator Eagleton had asked whether or not the Army had any scientific testing evidence to show the relationship of mobility agility in a combat vehicle and its survivability."

11, p 1

2. "Probabilities of survival on straight courses with alternating acceleration and deceleration were computed for the four candidate tanks. Again the heaviest tank has the best chance of survival. Each tank had a better chance of survival while running the straight course at maximum speed than it did for cases of deliberate slowing down and accelerating. The hit probability in the latter case is smaller than in the case of the constant speed run; however, the increase in running time allows the enemy to fire more shots, and hence the survival probability on the total run is smaller."

13, p 4

3. "By combining...relations...we obtain a mathematical model which expresses the probability of survival as a function of horsepower per ton... Such probabilities were computed for vehicles with dimensions such as those of the M113A1 APC on 200m runs at ranges from 500 to 3000m. The horsepower per ton was varied from 10 to 100. The results show that the relative gain in probability of survival due to increased horsepower per ton is appreciable only when this probability is low as it is at a range of 500 or 1000m when lag time is short. Of course, the absolute gain remains small since even a vehicle of 100 horsepower per ton has less than a 7% chance of survival at a range of 1000m. At longer ranges with a lag of 4s or more the survival probability increases rather rapidly at low horsepower per ton and levels of beyond 60 or 80 horsepower per ton depending on the range and lag."

13, Incl 4

4. "The effect of gunner lag on the miss distance against a maneuvering tank is considered. The analysis includes what might be considered as optimum maneuvers for the vehicle given limited velocity and acceleration. The analysis also considers an optimum (r.m.s.) prediction for the gunner. Gunner lag, if it is a couple of seconds, can be the most significant source of aim error for predicted fire. With large gunner lags, maneuver can reduce the kill rate by an order of magnitude or so."

19, Rpt Doc Page

5. "• Lag error is a very major (if not dominant) source of error in shooting at a maneuvering target.

"• Prediction can reduce the error only a limited amount. The only truly effective solution is to reduce the lag error, or else be prepared to shoot many more rounds.

"• Maneuver may be a very important mode of protection against predicted fire weapons."

(19), p 5

6. "...consider two campaigns...a battle at A followed by a battle at B and...a battle at B followed by a battle at A...order may be very important...Let AB cover entirely natural terrain...Suppose resources are available to modify the terrain in some sense (obstacles?). Represent modified site A by A' and modified site B by B'.... Now consider some new campaigns: A'B, AB', and A'B'...where as the obstacle advocate expects all these to produce better results than the base campaign AB, we have encountered some model results in which A'B produced an inferior result. The only plausible explanation was that, by prolonging the battle at A, the defender inadvertently allowed the attacker to apply reinforcing units to the later battle at B...the now strong attack did much better overall..."

(23), p 17

7. "Of the three fleet alternatives examined, the current fleet with a mixed composition of standard and cargo vehicles appeared to offer a good compromise for effective performance of general cargo and ammunition missions...These results indicate that the proportion of high mobility vehicles in current brigade TOEs can be significantly reduced and that the most likely candidate for replacement is the GOER family of vehicles."

(32), Vol 1, p 5-8

8. MG Decker (TARADCOM) stated as an objective of the TARADCOM, TARCOM and TRADOC community: "provide combat and tactical vehicles to win the land battle."

MG Hunt (DAPLOM) stated that "firepower plus survivability is a function of the weapon system"...that "until we arm carriers (APC) they will not contribute to the central duel."...that "TRADOC is our user."

COL Kelly (TRADOC) stated that "effectiveness is firepower times survivability"...that "TOW is the softest weapon but attrits at the longest range"...that even longer ranges for TOW type weapons are needed...that "the M60 will be in the fleet well beyond the 1990s" therefore effort expended on its product improvement is important."

(34)

9. "...(HERO) undertook a study of 19 battles of armored forces to determine the relative effectiveness of superiority in the fire-power, protection, mobility and numbers of tanks... As stated in the study, the results are based on a correlation between winning the battle and the superiority factors not on an analysis of cause and effect. That is, the study shows that the side with the more mobile tanks tended to win, but is not able to show that the tanks won because they were mobile."

35, p 22

10. "...results indicate a poor chance of hit when a lead angle predicting gun control system is used against approaching weaving targets, so we investigated an alternative system where a 'fixed' lead is automatically applied to the gun and the gunner fires just after the target begins its turn away from the head on altitude. The applied lead depends only on the range... This fixed aim-off method gave better hit chance."

36, p 7-A-1

11. "An advancing tank can reduce P_H...to 0.1 by performing a fast turn behind a smoke screen out of the way of an oncoming missile..."

36, p 7-C-1

12. "Thus far, the analysis of all three games at high and low mobility has not revealed consistent variation in attrition which can be attributed to movement rates...very little variation has shown up at all...the games have revealed that increased rates of movement may provide advantages that are very difficult to evaluate, with attrition measures, in the context of a war game."

36, p 7-D-3

13. "The requirement to play identical tactical situations utilizing the two levels of mobility has probably limited, at least to some extent, any quantifiable advantage which could be derived with higher mobility."

36, p 7-0-4

14. "As another type of Lanchester combat theory type formula, Peterson (4, 1967), indicates that for 1 versus n tank engagements in Northwest Europe during World War II tha first kill in such tank battles seemed to follow the "logarithmic law", whereas analyses of the second kill came closer to the Lanchester Square Law..."

37, p 9

15. "From the simulations and also from the theory developed, we also see the importance of firepower through either rate of fire, by going to a missile, or improving anti-tank gun technology... Whether we consider either the simulations or the theory, we have not been able to establish very clearly that mobility within current tank capabilities is of any great importance."

37, p 20

16. "A trade-off of mobility and armor can be defined as a relation between mobility and armor weight that shows how much additional armor is needed in order to compensate for the loss of mobility, i.e., the trade-off is an equation of the form.

$$\omega = f_M(m, E)$$

where ω is the armor weight and m is the mobility expressed in terms of the top cross-country speed, acceleration, turning rate, etc....E stands for a suitably defined index that measures the effectiveness of the vehicle in the mission M."

38, p 5

17. "...time may not be the critical measure of a battle. Range may be a more appropriate measure of rate of loss."

40, p 28

18. "The TETAM Extended Model shows that tank speed does affect tank survivability and influence battle outcome. As tank speed is increased, the offensive vehicle is intervisible for shorter periods of time; thus, the probability that the offensive vehicle will become engaged decreases. There is a reduction in defense--produced casualties, and the probability of the ATM firer breaking line-of-sight with engaged targets prior to missile impact increases... Tank speed effects are not sensitive to tactics employed by the attackers."

41, p 15

19. The results obtained from the DYNTACS-S Simulation in the TSSG study to determine the relationship between mobility and tank survivability are, in general, compatible with the results obtained from the TETAM Extended model study."

41, p 15

20. The AMSWAG Mobility Study

Mobility Characteristics (Phase I)

1. Normal Alternate Bounds at 30 kph (N30)
2. Paused Alternate Bounds at 45 kph (P45)
3. Normal Alternate Bounds at 45 kph (N45)

Phase I Conclusions

1. AMSWAG is sensitive to changes in speed
2. P45 not significantly different than N45 (see also Phases II and III)

45

21. "The effects of changing speed and changing direction of motion on survival of the very light and the heavy tanks of the 1972 design concepts are examined. The heavy tank is shown to be superior under the conditions examined in this report.

"An application of the HELAST II test data to our model supports our basic findings that the heavy tank is superior in spite of its lower mobility.

"It is further shown that optimal evasive maneuvers are safer than straight line runs when appreciable lag time exists."

47, p 3

22. "Player insights

- XM-1 speed gives a commander more time (and thus flexibility) to read the battle prior to commitment of reserves.
- XM-1 speed can allow positioning of reserves farther to the rear, out of medium artillery range.
- The MICV must be able to move as fast as the XM-1 (a study assumption)."

51

23. "These remarks throw light on the remedies for overcoming the present crisis in the development of new track and wheel vehicles.

- It is not a technology crisis. It is the user's lack of appreciation of the modern-time requirement to provide proper field data on the environmental and operational processes.
- The answer to the user's future needs for new ground vehicles is not, in all probability, a radical departure from either the track or the wheel; but it is probably a track-wheel mobility system which helps to accomplish the mission within the postulated probability of success, with maximum effectiveness and minimum cost of the equipment mix. (emphasis by author)

58

24. "In engagements of large numbers of 'adequate' tanks, the side with the greater mobility has usually been victorious, unless it was greatly outnumbered, or unless its tanks were seriously inferior in one of the other three major operational characteristics." (for cases examined)

59, p 34

25. "...Warsaw Pact forces would conduct a rapid, unceasing attack ...rather than engaging in a long war of attrition. The rapidity of advance and the type of weapons employed dictate that all elements have a high degree of mobility in order to sustain the advance, deny lucrative targets to enemy action by rapid dispersal, and mass quickly for offensive action."

61, p xix

26. "Warsaw Pact nations, and the Soviet Union in particular, have expended considerable effort to insure a high degree of mobility for their combat forces. This effort has been primarily expended on equipment capable of overcoming major obstacles and on retaining the capability to move and navigate under adverse environmental and terrain conditions ...Warsaw Pact emphasis on vehicle mobility is apparently directed toward preventing vehicle immobilization and ensuring continuous mobility, rather than emphasizing time-related factors such as maximum cross-country and road speeds."

61, p xxi

27. "...new advanced mobility combat vehicle programs can be and have been challenged by the two related questions:

- Can US ground combat forces effectively use this increased mobility potential in its fighting vehicles?
- Will new higher performance fighting vehicles be truly more cost-effective than current hardware or than new but less costly hardware with more moderate mobility performance improvements?"

64, p 2

28. "In each scenario, the fixed criteria for success (fixed effectiveness, E) was based on the requirement that sufficient force be deployed to decisively defeat specified enemy attacks on each of a series of critical objective points. The enemy attack start times, attacking force composition, and attack locations were assumed to be identical for all three mobility cases."

64, p 24

29. "...The dominance of the XM-1 tank was found to be primarily due to its armor protection and its capability to shoot accurately on the move. When a variety of complementary anti-tank weapons were added to alternative forces, simulation results showed that all of these reinforced Blue combat arrays did better against the Red opponents;...Blue force with the XM-1 tanks continued to hold the edge..."

65, Vol 1, p 2

30. "Cavalry's most difficult task is to see the battlefield and the enemy well enough to enable the cavalry unit itself or the main body to concentrate..."

68, p 1-7

31. "...For example, in an attack the commander must concentrate enough force in one area to defeat the enemy there. He does this by rapidly moving cavalry units to get superior odds, conducting a hasty attack, and exploiting the outcome of that attack. Through mobility the commander masses his forces in defense against an enemy main attack. If he is outnumbered 10:1, he maneuvers so he is outnumbered only 3:1 or 4:1. He changes the odds so he can break the enemy onslaught by destroying masses of enemy tanks and vehicles attacking at that point."

68, p 1-7

32. "Mobility offers other advantages besides concentration...Cavalry should...Move after shooting to avoid enemy artillery fire...Move out from under heavy artillery fire when it falls on team positions to an alternate position."

68, p 1-7

A.3 PERFORMANCE DATA

1. "Current assessment procedures are seldom related to the milieu of combat, but instead oriented more toward hardware performance while ignoring (except in passing) the human element...the vehicles (M60A1) suspension system was a major factor limiting vehicle mobility... due primarily to two contributing factors: (1) failure of the suspension system itself; and (2) limitations due to shock and vibration tolerances of the driver and (especially) the crew."

1, p 2

2. "Findings and Implications" [Relative performance of vehicle types]

1. 'Mobility/agility' still needs adequate operational definitions.
2. Factors which contribute to 'agility' also increase 'mobility'.
3. Agility is more than speed or simple acceleration.
4. 'Top speed' may not be a relevant measure of 'mobility/agility'.
5. Suspension systems were not a severe handicap to 'mobility/agility' (on this terrain and within these 'power' levels).
6. The X300 test bed vehicle was still 'power' and 'steering' limited for these type tactical courses."

4, p 15

3. "Findings and Implications*

1. The target center of mass of a combat vehicle maneuvering in a tactical situation presents a complex, non-uniform apparent motion to a weapon trying to attack it.
2. Appropriate exploitation of mobility/agility characteristics of a target will not only degrade the striking performance of enemy gunners, but also seriously increase the problems of effective lead requirements. This is especially noticeable in the rapidity with which lead requirements must be changed against highly agile vehicles.
3. Weapons performance measures obtained against targets moving at uniform velocities and directions may be considerably inflated over those to be expected against operational type targets.
4. The data suggests that gunners tend to consistently under lead a target, with a strong tendency to place the crosshair itself on target rather than the appropriate lead line."

4, p 21

*Phase I: Effects of mobility/agility on gunner's tracking performances and lead application.

4. "Summary*

"In general, the results of Phase II indicate that (1) exposure times, over this type of terrain, are short and, as expected, mobility does significantly decrease exposure time; (2) while target height has only minimal effects on target exposure, terrain structure and vegetation between the firer and the target decrease effective target size as well as cause intermittent target exposures and (3) there are gross differences in target appearance frequency when they are described with a resolution of 25 meters as contrasted to their description with a continuous resolution. The 25-meter description implies fewer obscurations and target exposures of a much longer duration than is actually the case."

*Phase II targets presented by tanks maneuvering under tactical conditions and the effects on target presentation of increased mobility/agility.

4, p 33

5. "Findings and Implications*

1. Increased mobility/agility of target vehicles can significantly decrease the probabilities both of being defeated and of being fired on.

2. Most rounds fired at tactical-type moving targets will be fired at targets which are only partially visible.

3. The concept of 'lay error' as previously defined and used may be of little value when applied to realistic, tactical-type targets. It may be more fruitful to consider the concept of aiming point.

4. A large proportion of targets which are successfully engaged present intermittent target exposures during the period of engagement.

5. The concept of missile shadow area, developed from the interaction of terrain influences and target movement, may be of considerable value both in the assessment of operational missile performances and for increasing combat vehicle survivability."

*Effects of increased mobility/agility on target engagement by enemy gunners.

4, p 61

6. ...tracking data of the field tests...HELAST II and High Horsepower Per Ton...Analysis of these data led to a hit probability model which showed that the earlier model did indeed exaggerate the effect of increased mobility. It also showed that a slowly moving target is harder to hit than is implied by many of the commonly used hit probability models."

13, p 2

7. "...it is most interesting to note the high degree of uniformity of results obtained on the M60 series tank regardless of the variety of terrain, test conditions, personnel involved, etc. It just looks as though the current tanks will produce a "speed made good" (simply distance divided by total travel time) of about 10 to 11 miles per hour regardless of most factors we are wont to consider as significantly affecting mobility/agility."

17, p 1

8. "The Swedish S-tank (STRV 103) incorporates design features unique to the current fleet of main battle tanks found in armies throughout the world...the STRV 103 is turret-less with the main weapon (105 MM) in a fixed mounting on the hull. In consequence, its gun is elevated or depressed by altering the pitch of the hull by means of an adjustable hydropneumatic suspension and traversed by turning the whole vehicle...accomplished by a clutch-and-brake mechanism for rapid turns and a hydrostatic drive for fine steering movements."

20, p 1

9. "The fixed gun design produces three desirable results. The first is the reduced silhouette afforded by the elimination of the turret... Secondly, the fixed gun eliminates the space within the armor envelope for movement of the breech, and allows for the provision of an automatic loader... Thirdly, since control of the main gun is by movement of the hull, the S-tank has integrated driving and gun controls. In an emergency one man can operate the tank."

20, p 1

10. "This ARSV study effort does not advance any conclusions, however, as to the increased combat effectiveness that is 'bought' due to the faster vehicle acceleration and reduced exposure time... In summary, the ARSV mobility test offers many insights into the performance of concept vehicles. The study does not, however, identify the relationship between mobility/agility and survivability. Prediction of speeds are informative but combat effectiveness in a realistic environment (forested terrain) that can be 'bought' by increased mobility/agility still remains unresolved."

21, Incl i, p 2

11. Dr. Pietsch gave us a tour of his facilities which, while relatively small (about 12 people), can produce a prototype vehicle of the FVT-02 type in from 18 to 24 months from concept development to hardware."*

*24 man-years at $60,000 per man-year = $1.4 M plus materiel.

22, p 2

12. "One very novel innovation was the passive stabilization system of the crew seats being tested in some vehicles, and especially the method of tying the gunner's optics to the stabilized seat. This allowed all crew members to more effectively absorb the shock and vibration of highly mobile vehicles and was apparently a practicable approach to the very serious problems associated with addressing optics in a moving environment. This is an approach which should be considered for assessment in the HIMAG program."

22, p 3

13. MinRat Stark's group represents...a treasure trove of valuable information for developing tank designs...with regard to thermal signature of combat vehicles...rather than try to reduce the thermal signature of vehicles for the purpose of defeating thermal imaging sights, it may be far more productive to 'enhance' the engine exhausts and thus result in a confusion of thermal images... Their use of auxiliary electric drive engines for both silent watch...and for operations requiring stealth... They are concerned with the vulnerability of optics and electronics to non-penetrating rounds...might result in a larger number of 'fire power' kills. They are investigating a variety of means for shock-mounting the optics and critical electronic equipment..."

22, p 5

14. "They [MinRat Stark's group] have been doing a considerable amount of work on smoke generators for combat vehicles. One such effort resulting from their concern with enhanced engine exhausts (because it places the smoke where the tank has been and does not protect the smoke-laying vehicle) was the development of a test rig which had smoke generators which projected smoke ahead of the vehicle, so that it was always traveling within its own smoke screen."

22, p 5

15. "They* have been doing some work on using indicator lights for giving directions, maintaining orientation of moving tanks, and command and control... Essentially they have found that the gunner loses orientation if his field of view is restricted to less than 25 to 30 degrees...they are now undertaking studies of the factors influencing the time required to shift fire from one target to another... will concentrate on the effects of firing shock on times to shift fire...it seems they now feel that neither daylight TV nor other current systems will compare with the performance of optics for all-around target detection and engagement.

*MinRat Stark's group.

22, p 6

16. "Minister Stark indicated that it was his task to develop and measure the optimum capabilities possible in the design of combat vehicles and to do this independent of cost. Then it would be the task of other analysts to assess these optimum performance vehicles on a cost effectiveness basis...five major areas of investigation are... the track terrain interaction...the track, suspension and hull interactions which cause nuance values to the crew...the relationships between hull and optics...the hull-seat relationship...the seat/man/optics interaction. And this may be the weakest link insofar as improved mobility may be concerned."

22, p 8

17. "How reliable are the 'official' individual weapon characteristics? Are they heavily based on one-on-one duel considerations?... It is not unreasonable to suppose that the practical maximum effective range of 10 attacking tanks differs from that of just two tanks."

23, p 10

18. "The drivers reported that TWISTER offered them little protection from jolts and jars...the drivers unanimously stated that this vibration problem was a major reason for their tendency to markedly slow down when crossing uneven terrain...the other major contributing factor to the drivers' cautiousness...was its perceived lack of stability...the vehicles center of gravity was much too high...a heavy electrical generator and other instrumentation had been placed atop the vehicle for...the experiment...blamed the high center of gravity on this vehicular configuration."

27, #2, p G-2

19. "...drivers more generally enthusiastic about the relative absence of high amplitude, high g vibration in the vehicle [Scout] when crossing rough terrain...felt their vehicle was highly stable due to a low center of gravity and would be practically impossible to turn over."

27, #2, p G-3

20. "More of the target vehicles, according to the M60A2 player/gunners, were particularly hard to track. There was a slight tendency to overshoot the track on both the TWISTER and the Scout when they made abrupt turns, but the players felt they corrected this error rapidly enough...The greatest difficulty in tracking either vehicle occurred when it doubled back in its own dust. The TWISTER was judged slightly more difficult to track...Several gunners felt it would be helpful if the reticle brightness varied from bright to dim as the gunner's telescope moved from bright sun to shadow."

27, #2, p G-4, 5

21. "The M551 player/gunners also found the target easy to track... comment on the usefulness of the variable 8 to 12-power gunners telescope, pointing out that the lower power was useful for target acquisition and tracking at short ranges, while the higher power was useful for time target tracking at longer ranges."

27, #2, p G-5

22. "The TOW mount had a slight tendency to overswing when tracking a rapidly moving target travelling at right angles to the launch tube's axis--further, an elevation error was easy to make if a target vehicle turned abruptly."

27, #2, p G-5

23. "The players found the DRAGON system somewhat difficult to use. They stated it was heavy, unwieldy, and tended to slip off their shoulders."

27, #2, p G-6

24. "The M60A1 tank performed as anticipated with speeds falling commonly in the 10-16 mph range during performance of maneuvers. The XM800 Armored Reconnaissance Scout Vehicle (ARSU) and XM808 TWISTER were expected to double the speed of the M60A1...speeds attained during maneuver execution were in the 15-25 mph range, 50 percent greater than the M60A1 but not nearly so well as expected."

27, #3, p E-3-1

25. "It is not possible to examine every combination of weather conditions, battlefield terrain, enemy threat, and interaction between various weapon systems. Therefore the relative importance of mobility and armor protection must be inferred from an analysis of a few properly selected cases. An approach to such an inference is discussed in Section II of this report.

47, p 11

26. "In any engagement, the firepower of the tank affects the enemy fire and therefore influences the relative merits of mobility and protection. However, it may be assumed that the threat remains constant during a maneuver that lasts only a short time. Thus armor protection and mobility can be studied independently of armament."

47, p 13

27. "Resolution of USAMSAA and USACAA Tank Speed Differences.

"...it appeared that the two agencies, using the same basic data were achieving different results.

"It was determined that the difference resulted from three causes:

a. Input data (early 'best' estimates versus later engineering estimates)

b. Terrain differential (two categories versus sixteen categories)

c. Tactical considerations (top speed versus degraded speed).

49-1, 2, 3

28. "Tanks are clearly mobile weapons platforms. More specifically they are means of making heavy, direct-fire weapons more mobile, and therefore more effective..."

57, p 41

29. "The extremely high cost of true cross-country vehicles is leading to development and procurement programs which match vehicle mobility to intended missions. High mobility vehicles are procured in small numbers and are assigned only to units requiring extensive cross-country logistical support. Typical missions for trucks in this category include support of armored units and the towing and resupply of artillery.

60, p xvii

30. "...Measures of effectiveness...Tank contribution (TC)... TC= Red tank and anti tank weapon systems killed by Blue tanks divided by total Blue tanks killed...total force ratio...TFR =

$$\frac{\text{Total Red tank and anti tank systems killed...}}{\text{Total Blue tank and anti tank systems killed}}$$

Total Tank Ratio...= $\frac{\text{Total Red tanks killed...}}{\text{Total Blue tanks killed}}$

Forward Edge of the Battle Area (FEBA) movement over time."

65, Vol III-II-3

31. "Table of Relative Speeds of Units

Unit	Foot		Trucks				Trucks				Army Aircraft	
	Day	Night	Day		Night		Day		Night			
			Road	X-6	Road	X-6	Road	X-6	Road	X-6	Fixed Wing	Rotary
Individual	1	.8	6	4	4	2	10	3	4	2	70	50
Platoon	.9	.7	5.7	3.7	3.7	1.7	9.7	2.7	3.7	1.7	70	50
Company	.8	.6	5.5	3.5	3.5	1.5	9.5	2.5	3.5	1.5	65	45
Battalion	.7	.5	4.5	3.0	3.0	1.0	8.0	2.0	2.5	1.0	60	40
Brigade	.6	.4	4	2.0	2.0	.7	7.0	1.5	2.0	.7	45	30
Division	.5	.3	3.5	1.5	1.5	.5	5.5	1.0	1.5	.5	20	10

Note: Speeds shown are for the attack when contact is imminent..."

66, p 1-B-54

32. "Vehicular mobility is a support function, applied to moving men and equipment as required in combat situations to apply firepower, perform reconnaissance and surveillance, furnish supplies, establish or evacuate positions, provide mobile command and communications posts, and facilitate construction and engineering operations."

69, p 1

33. "Any vehicles constrained to move within cities will have doubtful survivability when confronted by heavily armored opposition."

70, p 5

34. "In light to medium fire situations, current armored surface vehicles can move and survive."

70, p 28

35. "Breakthrough vehicles had to be heavily protected and carry heavy guns. These ponderous vehicles had limited mobility and were expensive. For exploitation speed, range, reliability and cross-country mobility were important."

70, p 34

36. Liddel Hart described the T-34 in terms that can still be used to describe Soviet weapons: "The machines were rough inside and out... Their design showed little regard for comfort of the crew. They lacked refinements and instruments that Western tank experts considered necessary as aids to driving, shooting and control...

"On the other hand, they had good thickness and shape of armor, a powerful gun, high speed and reliability...the four essential elements. Regard for comfort and the desire for more instrumental aids involve added weight and complications of manufacture. Such desires have repeatedly delayed the development and spoiled the performance of British and American tanks"...

70, p 65

A.4 QUANTIFICATION TECHNIQUES

1. "The Ad Hoc Group on Ground Combat Mobility was charged with studying and evaluating the methodologies in use by the Army for defining future ground combat mobility requirements and promoting new advances in ground combat vehicles. Aside from military judgement and combat experience, the principal tools in use are simulations in a variety of forms..."

6, p 1

A.4.1 Testing

1. "HELAST II had three major objectives:

"1. To measure the effects of increased mobility/agility of a tank target on a defending gunner's tracking performance and lead requirements.

"2. To describe, in detail, the target presented to an enemy gun position by a tank moving under tactical-type conditions, and to determine how that presentaiton is affected by increasing the mobility/agility of the target tank.

"3. To investigate how target mobility/agility affects target engagement by enemy gunners; in terms of probabilities and times of target detection, identification and (simulated) fire."

4, p 1

2. "Both forces had essentially total freedom to maneuver in the test area* to include within small villages...Position location instrumentation, for the attacking force and direct fire simulation for SWINGFIRE and MILAH were two major shortcomings observed during the test...Conceptually, the US may have been able to provide an accurate and reliable position location instrumentation (i.e., DDR&E, RMS) on some if not all of the test sites."

*North German Plane.

7, p 2

3. Test Objectives

"...to evaluate the combat effectiveness of the features of the S-tank which might be considered in the design of future vehicles.

"...to compare the performance of the S-tank with existing tank systems.

"...to evaluate the effects of mobility, agility, and silhouette on tank survivability."

20, p 2

4. "Two Swedish S-tanks will be available for test purposes and two M60A1 (with add-on stabilizer) tanks will be operated and fired concurrently with the test vehicles for direct comparison..."

20, p 2, 3

5. "Data recorded...and collected...will provide a basis for comparative analysis with existing Army tank systems, and inputs for the AMC Mobility Model and Tank Exchange Model. In addition, data will be collected to provide future inputs to the Dynamic Tactical Simulation. These models will be utilized to provide a systematic overall evaluation of the S-tank."

20, p 4

6. "The following objectives were to be examined during the first phase of the survivability field experiment...the effects of constant speed on vehicle survivability...the effects of evasive tactics on vehicle survivability...Obtain data for comparison of vehicles in the areas of mobility and agility...the firing performances of four different firing systems against agile targets."

25, p 1, 2

7. "This report describes the results of research and analysis... concentrated in two major areas...The Swedish S-Tank Agility/Survivability Test (STAG) to be conducted at Fort Knox during the last three months of 1975...Analysis of apparent acceleration and velocity of a moving target relative to a stationary firer."

26, p 1

8. "ATMT Objectives

"Determine ability of gunners to track evasive targets.
"Determine performance of ATGM's against evasive targets.
"Develop data base..."(To improve ATGMs).

44

9. "[Phase II] the Force Development Test and Experimentation... was designed to provide operational test data on the ARSV subsystems... for subsequent comparison of alternative scout vehicles, particularly in the areas of operational mobility, agility and signature..." [Reference 55 includes Phase I (Reference 56) and Phase II as described above.]

55

A.4.2 Modeling

1. "Conclusion No. 4 - Among the more important of the currently available simulation models with combat mobility implications are the following: at the division level--DIVWAG; at the battalion level--DYNTACS, IUA and CARMONETTE; at the engineering level--AMC Mobility Model."

6, p 30

2. "...AMC established TACOM in 1970 as the lead laboratory in ground mobility research and chartered this command with the responsibility to coordinate activities in this technical area. This community is currently composed of TACOM, Waterways Experiment Station, Cold Regions Research and Engineering Laboratory and numerous industrial and academic institutions. A principle product of this team effort is the development of the AMC Mobility Model..."

18, p 1

3. "This model is a comprehensive computer simulation of the mobility performance of a vehicle system (including the crew) over a carefully specified geographical area."

18, p 1, 2

4. "The machine, or vehicle, data inputs are those characteristics of the vehicle system which are required to predict the dynamic response of the vehicle concept as it moves over the terrain profile...A systematic presentation of the terrain features to which the vehicle is subjected is the next ingredient for the model...Human tolerance to vibration levels is the third main ingredient in the mobility model."

18, p 2, 3

5. "The output of the model takes a variety of forms. The time to go between two points along a straight line can be computed. Route selection based on minimum elapsed time is available. In addition to these detail outputs, generalized information can be obtained. One such generalized output is the velocity profile. It is simply the presentation of cumulative average speed as a function of the percent area covered...Additional outputs are available. Fuel consumption for vehicles can be computed using the model. For vehicles used in air defense roles the percentage of total area available for deployment, the amount of terrain masking, and time required for emplacement can be calculated."

18, p 4

6. "We agree in general with your concern over the current lack of an Army effort on the trade-offs of mobility/agility/armor protection and the added value of mobility/agility in general...our current approach involves examining the value of mobility/agility through the

the assessment of one-on-one engagements between AT guns and missiles and tanks of various mobility/agility capabilities, the conduct of small unit engagement simulations using AMSWAG (AMSAA's modification of the Border/IUA model) and through the play of a brigade level game in which we are attempting to judge the value of tactical mobility."

21, Incl g, p 1

7. "Of the two, operational mobility is more amenable to analysis and significant progress in establishing models of it has been made with the AMC 71 Mobility Model and the Army Mobility Model (AMM 75). However, both models are at present open to the objection that they involve the characterizations of soils only by means of cone penetrometers and, even more, because they characterize the ability of vehicles to cross soft ground by means of empirical cone index values. Their value is consequently limited, particularly with regard to evaluating the mobility of vehicles radically different from those in use, and further work is necessary on the development of mobility models at wider validity."

30, p. 13, 14

8. "Based on the survey, we felt that three mobility/agility method improvements were necessary...develop modules for one or more models of combat of the interaction between the agility of a target vehicle and the accuracy of threat weapons attempting to hit that vehicle...develop a probablistic model which accurately portrays the interaction between agility of a target vehicle and the pattern of line-of-sight 'windows' presented to opposing weapons...develop a division/corps level model which will explicitly account for the contribution of battalion level mobility to force effectiveness."

33, p 1 and Incl 2, p 2

9. "... employing the TXM. The model is a Monte Carlo calculation of a tank battle in which a fixed number of assaulting tanks approach, on predetermined paths over deterministic terrain, a position defended by a fixed number of enemy tanks. The defensive tanks are stationary during the engagement. The battle proceeds according to Monte Carlo calculations of detections, decisions to fire, hits, kills, etc. Since the model is probabilistic, the engagement is repeated many times to obtain average results. The primary result of interest is the exchange ratio, defined as the total number of enemy tanks killed over all repitions divided by the total number of US tanks lost...the number of tanks on each side is critical to the exchange ratio for a single case."

35, p 34

10. "Because the defensive tanks do not move in the cases analyzed, the effects of increased mobility can only be explored in those cases

in which the M60A1 is assaulting. This variation was accomplished by varying the forward speed by a factor γ, the 'speed multiplier'."

35, p 86

11. "The Extended TETAM Model is an empirical model based on the results of a series of two-sided, real-time, casualty-assessed field trials (TETAM Phase III).

"(The purpose of TETAM Phase III was to gather data for a defensive ATM platform opposing a Soviet reinforced tank company from two-sided, free maneuver, real-time casualty assessment field trials.)"

41, p 2

12. "AMSAA has generated 72 runs with the AMSWAG model. The results of these cases are summarized...The first 64 cases...address all combinations of the following study parameters:

a. Protection (XMI or M60A3)
b. Mobility (XMI or M60A3)
c. Attacker maneuver force (pure tank or infantry heavy mixed tanks and APCs)
d. Attacker overwatch weapons (tanks or TOW)
e. Defender force (pure tank or pure missile)
f. Starting range (3000 or 1000).

42, p 2

13. The AMSWAG Mobility Study

- Situation
  - Routes — Forces (No., Effectiveness Data,
  - Terrain — Vulnerability)
- Mobility Characteristics
  - Input
    - Vehicle Data
    - Terrain Data
  - Output
    - Maximum Velocity
    - Time to Accelerate
    - Distances to Accelerate
    - Time to Decelerate
    - Distances to Decelerate

45

14. "A sufficient number of battle conditions...should be examined and the dependence of the probability of survival of a tank on these various battle conditions should be determined...This relation between battle conditions and survival probability should be used as an input in combat models that include detection (intelligence) and firepower

of the attacking tanks, the resulting attrition of opposing forces, and other changes in battle conditions."

47, p 42

15. "...once a battalion with XMI speed started fighting in TARTARUS, its movement rate was the same as if it had M60A1 speed. That is to say our game measured what the added speed of the XM1 contributed in terms of getting reserve battalions into the battle, but it did not measure any advantages that could be accrued from the speed after the battalions commenced fighting. Likewise, we did not credit the XM1 cases with the other potential XM1 advantages such as agility, survivability and fire power."

51

16. "Units with XM-1 speed in the forward assembly area had a great deal more time for command and control, logistics and general attack preparation. Again, this advantage is not measured in the TARTARUS output."

51

17. "The purpose of the present report is basically three-fold:

a. To document the status of Lockheed IUA development at AMSAA;

b. To provide additional input and output information related to the runs made for the XM-1 Independent Evaluation;

c. To present and discuss results of certain additional runs that were made with the IUA program.

"The IUA simulation program provides a means for studying the interaction between a battalion-size attacking maneuverable force and a deployed defensive force..."

62, p 11, 12

18. "The Mobility portion of the overall IUA program uses the Variable Data to determine which vehicles are being played, to which routes they are assigned, and the mobility characteristics of the vehicles such as speeds versus soil types, speeds versus gradients, and speeds as a function of tactics, obstacles and visibility conditions."

62, p 20

19. "Theoretically then, it would seem to the layman that there are no technological reasons why the overall mobility and combat effectiveness of large mechanized combat units up to and including division-size task forces cannot be increased significantly.

"But many other factors in addition to increased mobility of individual combat vehicles are involved in converting from the 'theoretically possible' to an 'actually obtainable' increase in mobility.... For example, the average rate of movement of large maneuver units is constrained by the capability of the surveillance... and by the speed of the command/control/communication process itself... Once in motion, large units are further constrained by the slowest vehicles in the march columns..."

64, p 2

20. "After the penetration, an Armored Cavalry Brigade task force is given the mission of passing through the U.S. Corps and leading its exploitation...

[In a second scenario, a] Brigade is sent on a deep raid around the southern flank of the guerilla infested area...

[A third scenario contains] a delay phase, wherein four Armored Cavalry Brigades operating as a screen conduct a systematic delay..."

64, p 18, 19, 20

21. "Models... CARMONETTE... Battles at varying force ratios and different postures...are simulated in this as input to the casualty assessment routine of DBM... Division Battle Model (DBM)...manual wargaming model with combat aggregated at company or battalion level... This analysis emphasizes the measurement of mobility... TARTARUS... A computer-assisted, corps level, wargaming model with combat aggregated at the battalion level. Used to determine the result of changes in unit mobility in terms of FEBA movement."

65, Vol. III, p II-2

22. "...when contact was made in DBM, no additional contribution of mobility was measured...the mobility differential is based solely on movement to contact."

65, Vol. III, II-10

23. "...Model Results ... (DBM)... In many cases the movement was to blocking positions and because of the short movement distances involved, both high and low versions arrived in sufficient time to

prepare the position prior to contact... For those unit moves undertaken to accomplish a reinforcing mission... The mobility differential is expressed as the percentage of nominal battle time that the reinforcing unit is engaged.

65, Vol. III, p II-20/22

24. "...The TARTARUS outcomes at the division level support those that resulted from DBM..."

65, Vol. III, p III-59

25. "...<u>Maneuverability Analysis</u>... The battalion level high resolution model results were used to obtain a measure of the contribution of tank maneuverability to the overall operational effectiveness of the tank. DYNTACS and CARMONETTE results were used in this analysis..."

65, Vol. III, IV-19

A.4.3 Analytic

1. "Table 2...shows the entry order of some of the variables into regression equations for the 17 trials available. The table indicates that the apparent motion parameters (apparent velocity and apparent acceleration for example) explain variations better than strict motion parameters. Velocity is an exception to this. Very little contribution to gunner and target errors is caused by the 'normal' motion parameters (accelerations, aspect change, etc.)."

24, p 4

2. "Table 3...shows the final R for the regression. The gunner error, target induced error, and 'true lead required' show the best promise of explaining variations. The actual recorded errors (total AZ and EL) show the least promise."

24, p 3

3. "In almost all cases, the apparent motion variables explained a significantly larger portion of the variance observed in the dependent variables than did the straight motion variables...the 'computed gunner error' variables (which are of prime interest) yielded much higher R^2 values (generally in excess of 0.7) indicating that apparent target motion significantly influences gunner performance."

25, p 13

4. "The results of the analysis conducted for this contract period have provided significant insights into the effects of mobility and agility on gunner tracking and hitting performance. These results will be validated from the High Mobility/Agility Test results to be conducted during 1977."

25, p 13

5. "...there appeared to be some differences in the mobility data used by AMSAA and CAA in their respective war games, although there was no difference in final conclusions...the poor correlation of road speeds is explanable when underlying assumptions are understood... All differences in speeds and time differentials have been explained and resolved in terms of the size of the unit being moved, tactical and command and control considerations and assumptions concerning the nature of the road net. Because cross country travel was not a significant movement made in either war game, the assumption on roads became a dominant factor."

29, p 1, 2

6. "...fine details of the control and coordination of the exposure periods of the individual weapon systems engaged in a battle are a principal determinant of the predicted combat results of the engagement."

31, p i

7. "This analysis was conducted...as a part of a larger US Army study effort...addressing the comparative performance of standard mobility versus high mobility tactical vehicles...objectives...were... determined the capability of standard and high mobility vehicles to maintain the combat potential of a brigade...identify a preferred mix of standard and high mobility vehicles...determine the adequacy of the porposed basis of issue...the GRC effort was limited to analyzing the comparative performance of three vehicle fleets."

32, Vol 1, p 5-1, 5-2

8. "The methodology used in the study was to analyze each of the candidate tanks in general cases using the TXM...Each case was analyzed twice: once with ten friendly tanks moving against five T-62s in defensive positions, and once with ten T-62s moving against five friendly tanks in defensive positins..."

35, p 12

9. "...an analysis of mobility was conducted to determine its effects on tank performance...the results of this analysis are not conclusive either for or against high mobility. Increased tank mobility may be advantageous in two different ways: (1) in reducing the duration of exposure to enemy fire and making the tank harder to hit, and (2) in reducing the time for deploying and moving forces. For the latter, increased mobility permits a more rapid concentration of forces, aids the tanks to bypass known enemy strong points, and makes possible the more rapid exploitation of breakthroughs."

35, p 20

10. "For the purpose of this analysis mobility was considered as the ability to traverse a given piece of terrain and the average rate at which it could be traversed. Agility represents the ability of a vehicle to change quickly its speed and, or direction at travel. The study attempts to examine the mobility/agility at three levels... the 'one-on-one'...one weapon trying to hit a maneuvering target... the second...is the effect...on small unit actions...the third phase...examines the effects of individual vehicle mobility on unit movement and tries to measure the combat value of incremental improvements."

36, p 7, and D-1, 2

11. "We now formulate the problem somewhat specifically and analytically in order to study the relative importance of mobility, armor protection and fire power for tanks, by assuming exponential life times because we believe that many battles may so be described."

37, p 14

12. "The purpose of this study is to examine TETAM Extended Model data output to evaluate the effect of tank speed on survivability. The following measures were used:

- Probability of an offensive vehicle not being engaged by the defense
- Number of tank casualties sustained by the offense
- Casualty exchange ratio
- Number of times offensive vehicles are engaged by the defense
- Probability of defensive firer losing line-of-sight with target prior to anti-tank missile impact.

41, p 1

13. "Principal Assumptions and Data for Mobility/Protection Studies

1. Approach

The performance of a tank and of a tank gun were divided into elementary functions...

Our studies involved various combinations of probability distributions of the followng random variables:

1. Apparent speed of the target
2. Apparent acceleration of the target vehicle
3. Total exposure time on a specified cross-country run
4. Aspect angle...
5. Range to target.
6. - 15. (various gunnery parameters)."

43, Incl 1, p 1

14. The purpose of this analysis is to determine the effect of mobility and agility on the probability of hit and the probability of survival of an ARSV and also to relate these probabilities to the vehicles used in the high horse power per ton tests at Fort Knox in August 1974."

46, p 9

15. "The purpose of the current studies at BRL is to develop a series of mathematical models that can provide...inputs for the study of the total systems."

47, p 13

16. "Study Task

"...From the standpoint of tactical and strategic mobility and within the constraints of the baseline force structure, determine the optimum mix of towed and self-propelled field artillery required

at corps and higher echelons to support worldwide contingency plans...The study includes consideration of the operational capabilities of artillery weapons in terms of ground mobility..."

52, p xi

17. "Tactical mobility:

"The European ground mobility and analysis evaluated... candidate mixes...and ranked them in order of preference from the most mobile to the least mobile. The basis for mix rankings was a qualitative ground mobility analysis which permitted computation of weapons availability in firing position as a function of system ground mobility."

52, p 6

18. "The basic question in the evaluation of tank designs is how successful the different tanks might be on the battlefield.

"What can be done...is to estimate the chance, or probability, that the tank will perform a battlefield mission and then to compare the effectiveness of different designs on that basis."

57, p 132

19. "...summarizes a comparison of the relative cost effectiveness of the XM1, M60A3 (RISE), and M60A1 (AOS) tanks. Three high resolution simulation models were used to evaluate Europe and Middle East scenarios developed from SCORES. The Tank Exchange Model (TXM), CARMONETTE and DYNTACS. The Concept Evaluation Model (CEM), was used to evaluate tank alternatives in a theater level campaign. Cost effectiveness was evaluated using the results of battalion and theater level simulation. The results of battalion and theater level simulation and relevant 15-year life-cycle costs. An Excursion was conducted using two models, TARTARUS and the Division Battle Model (DBM) to evaluate the contributions of tank automotive performance to net unit mobility."

65, Vol I, p Rpt Doc Page

20. "Mobility Analysis...to determine the impact of tank automotive performance on unit mobility. Two simulation models were used; the Division Battle Model (DBM) and TARTARUS. Using European scenarios, tactical situations were portrayed requiring rapid displacement of company and battalion size units. The contribution of tank mobility to unit mobility is reflected through differences in battle assessment..."

65, Vol. I, p I-3

21. "Excursions - when equal size and equal cost forces were simulated using the M60A3 as the base tank, the superiority of the XM-1 diminished somewhat."

65, Vol. I, p II-10

22. "...The CARMONETTE excursions and the analysis of the DBM games indicate that the M60A3(+) is not able to take full advantage of its increased mobility in the defense in battalion level combat due to its increased vulnerability relative to the XM-1."

65, Vol. III, p II-11

23. "...The model used in the ARAFCAS simulations is...DIVOPS... The principal measure of effectiveness used was the final position of the FEBA at the end of 24 hours of combat... Sortie requirements for the division will increase significantly...if scatterable mines are not employed."

67, p 5, 7, 18

A.5 TRADE-OFFS

1. "...the primary purpose of the study might well be rephrased to answer the question: 'Are senior Army officials being provided accurate and comprehensive data and information as a basis for arriving at sound decisions regarding major resource allocations to satisfy future Army combat mobility needs?'"

6, p 7

2. "In the design of combat systems, including combat vehicles, there are three broad defined steps in the process: conceptualization, optimization of subsystems and, finally, detailed design...For the first step the primary input is subjective judgement...techniques must be available to optimize the design approach as the second phase of the design process...The third step...consists of detailed engineering procedures."

6, p 19

3. "Evasive maneuvers are not straight course runs; therefore, the survival probabilities of the conceptual tanks were computed for serpentive paths of various kinds. The probabilities of surviving runs were computed for paths with periodic deviations left and right (sinusoidal path). Then the amplitude and the frequency of the left and right deviations that produce the best chance of survival for each tank was examined. In all cases, the heavier, i.e., better protected tank, fared better than the lighter tank, in spite of the associated reduction of mobility."

13, p 3

4. "A light tank with little armor protection improves slightly if its mobility is increased. However, a greater gain in survival is achieved by increasing the armor protection even at the expense of reduced mobility. The probability of survival increases more rapidly as the armor protection approaches the level at which the conditional kill probability becomes small."

13, p 3

5. "...survival probabilities for each of the four tanks were computed on S-shaped runs, i.e., on courses composed of semicircles. In general the heavier tank had a better chance of surviving the lighter, although at ranges of 2500 m and beyond, the chances for both were equal, provided substantial gunner's lag existed."

13, p 4

6. "...refer you to a soon-to-be published BRL report by Dr. Ceslovas Masaitis...he derives curves of survival probabilities as a function of horse power per ton ratios. His preliminary results would indicate that one essentially buys increased survivability with increased power up to about 60 or 80 horse power per ton before

the curve begins to flatten. (It is interesting to note that current hypermobility test rigs developed by the Germans and the British are in the 60 to 80 horse power per ton ranges.)"

16, p 1

7. "Trying to get increased mobility for a HELAST II vehicle, we pulled the turret off an M60, hoping to improve performance through increased horse power per ton ratios. However, we found no measurable difference in performance with or without the turret...on COBRA/TOW OT II, we added over 4 tons of armor plate to the M48 A3 modified to the ETT. Also, this shifted the center of gravity to the rear so that the tank was tail heavy, with a serious nose-up altitude. Surprisingly, this seemed to improve vehicle performance as it outran, and especially out maneuvered, all M60s available. (The PM of ARSV told me they found the same thing when they shifted the center of gravity to the rear.)"

17, p 1

8. "In my own mind, I currently doubt our need for very high horse power per ton ratios as a prerequisite for high effective levels of mobility/agility especially if low end performance is more important than high top-end performance on the real battlefield."

17, p 5

9. "As exposure time decreases, the survivability of a target vehicle clearly increases since fewer rounds can be fired during the exposed interval...As a vehicle deviates from simple, slow and predictable paths of movement it becomes less susceptible to accurate tracking and engagement by an enemy gunner. Survivability, therefore, is enhanced by increased complexity of motion. Increased agility may also have a negative effect. As vehicle motion becomes more rapid and erratic, initial detection is simplified for enemy observers and engagement may take place at longer ranges."

21, Incl i, p 1

10. "What already outnumbered force will have enough time and energy to create obstacles? And if the creation of obstacles has a multihour or multiday lead time, how does the defender know where to put them?...How can anyone be sure that unrestricted defender mobility for counterattacking is not more valuable than restricting the attacker's mobility...Is there a significant risk that the stopped attacker can more easily detect defenders, more rapidly serve his weapons, and more accurately fire?"

23, p 12

11. "Letting a few attackers through at a time may let the defense divide and conquer the attack in detail."

23, p 13

12. "The usually cited evidence about the strategic uses of obstacles seems to fall into two categories...Obstacles and fortifications do appear to have swung final outcomes, but the time and effort to create these obstacles and fortifications are expected to be beyond practical consideration for Western Europe...Lesser obstacles and fortifications may have had some effects but did not swing final outcomes from defeat to victory. That is, many obstacle-related campaigns seem to have led to the same result as would obstacle-free counterparts; winners and losers would have not reversed roles..."

23, p 29

13. "...it seems that obstacles can restrict an enemy's freedom of action and condition him in ways helpful to friendly forces... the uncertainty in the enemy's position may be reduced. Or...the uncertainty in the enemy's time of arrival or departure may be reduced. In the sense that good intelligence reduces uncertainty, obstacles may have some intelligence-like equivalence."

23, p 47

14. "...assume force ratio to win then look to see what mobility differential would have allowed you to get that ratio given dispositions of firers, i.e., reserve."

27, p 1

15. "The German Ministry of Defense is assiduously pursuing future tank technology under the creative direction of MinRat STARK, Department RUE-VII 6 at Bonn."

27, Trip Rpt, p 1

16. "Heavy armor was eschewed in favor of mobility-agility based largely on a mathematical analysis which showed that steady state targets could suffer a hit probability of .80 in modern combat. The analysis when pursued further predicted that a 60 degree slalom course as a mode of travel would reduce hit probability to below .20 provided, of course, that apparent motion could be altered rapidly as a function of time."

27, Trip Rpt, p 4

17. "The TVFS model results demonstrated that the great majority of missions were performed at least equally as well by standard vehicles as by high mobility vehicles. As mission routes increased in distance the special mobility characteristics of the HIMO vehicles were less important to timely mission completion. In fact, the HIMO vehicles were penalized by their comparatively slower on-road speeds. Even for dry, partially off-road routes, the advantage of the HIMO vehicles was small. For partially off-road routes under more adverse weather conditions, certain HIMO vehicles were especially superior...for approximately 10-30 percent of resupply missions."

32, Vol 1, p 5-7

18. "The purpose of the study is to provide a comparative evaluation of possible US main battle tanks. The study has considered selected existing tanks, tanks and tank systems that are proposed for development, and some possible future tank designs...tanks are compared in their operational effectiveness in small unit, tank versus tank engagements, and in their vulnerability to a representative antitank missile...in Section E, a separate analysis of the effects of mobility is described..."

35, p 1, 3

19. "Thus, for tank combat, and with due consideration of its critical nature, we see that multiple hits are required to guarantee high assurance of a kill, and hence that the firing and adjusting of single rounds may amount to inadvisably low rates of fire. Indeed, rate of fire, and even the simultaneous launching of several antitank rounds, therefore, appear to be of such importance as to perhaps guarantee survivability on the battlefield."

37, p 8, 9

20. "Concerning acceleration of the vehicle to avoid being hit, Reed (6, 1973) indicates that generally speaking, maneuvers of the vehicle, to be very effective would have to attain rather high accelerations...Thus, it would appear that any attempted evasive tactics, other than perhaps sudden turns, on the part of a tank to avoid being hit may not be very effective."

37, p 10, 11

21. "In view of the results..., one may conclude that reduction of exposure time and increase of the lead angle error by the increase in speed are not sufficient to make it advisable to trade the armor weight for speed. The situation may be reversed only if the advantages of speed are enhanced by additional circumstances."

38, p 24

22. "Therefore, both mobility or fire power as well as catastorphic kill probability must be considered when comparing the relative efficiency of the vehicles."

39, p 12

23. "Increasing the amount of conventional armor reduces the mobility and agility, but provides very little protection to suspension, tracks, and gun tube. Therefore, the mobility/fire (power) kill survival probability decreases as more weight is added."

39, p 12

24. Survival probabilities are computed for tanks running on straight courses as well as on serpentine paths while under direct fire. Both mobility or fire power and catastrophic kill probabilities are used in the computation. The results show that lighter vehicles with conventional armor...fare better than the heavy ones when mobility or fire power loss is considered. In the case of catastrophic kill, heavy vehicles are much better than light ones, but light ones are slightly better than medium weight vehicles."

39, p 11

25. "The results of these cases indicate that increased speed is advantageous to the attacker. It enhances his survivability and it allows him to close with the defender position and to inflict more casualties on the defender.

"...the ability to move faster is more important than the movement technique used while moving faster. The relative importance of speed and movement techniques is worthy of further investigation."

40, p 29

26. "Future Applications (of ATMT results/data)

- In design evaluation
  - Set design goals for new vehicle designs by translating maneuverability into survivability
  - Evaluate competing designs from the standpoint of survivability
  - Quantify effects of maneuverability improvements on survivability
- In training
  ..."

44

27. "No field test, nor even a theoretical investigation, is necessary to prove the obvious fact that increased mobility or agility improves the chance of survival of a tank. However, it should be emphasized over and over that all the tests and theoretical studies performed up to now indicate that it is indeed a poor bargain to buy mobility by reduction of armor."

47, p 41

28. "The purpose of this report is to develop and illustrate methods of applying analytic trade-off techniques to armored vehicle design evaluation. The problem areas of concern are the use of these techniques in the selection of optimum design points when user requirements and the state-of-the-art are in conflict... The interrelationships between composite system measures such as gross weight, cost, etc., and selected performance requirements (range, speed...) are analyzed. Trade-offs of performance parameters in terms of weight and cost are then calculated."

53, p i

29. "This study represents an illustration of the application of the aircraft growth factor and trade-off technique knowledge to the automotive vehicle field."

53, p iii

30. "Unfortunately, the factors of mobility, firepower, and protection while important in themselves are in conflict with each other to the extent that each demands an allocation of seriously constrained gross tank weight and cost...

"...a comprehensive understanding of the trade-offs of performance parameters in terms of gross vehicle weight, cost and combat effectiveness."

53, p 1-2

31. "Mobility parameters include such factors as grade-speed combinations, acceleration and braking capabilities, obstacle clearance, free board requirements, combat range [and] ground pressure. Gross weight could, in fact, be included as a mobility parameter particularly if strategic mobility is considered."

53, p 2-5

32. "The exercise was conducted for the purpose of determining the interrelationship of the Armored Reconnaissance Scout Vehicle with the other elements of a cavalry platoon."

54, p iv

33. "In weighing the combat advantages of superiority of numbers of tanks against the advantages of qualitative superiority of specific characteristics of tanks, superior tactical mobility is most important and numerical superiority is next after mobility in influence upon the outcome of armored conflict."

|Major conclusion|

59, p vi

34. "We believe that in those situations where there is no choice but to expose ground-mobile, direct fire weapon systems at line-of-sight ranges against a proliferation of enemy weapons which preclude the use of agility or terrain to escape hits, and which cannot be destroyed or suppressed in advance of our own exposure, light armor to stop fragments and small calibers is not enough. Heavy armor is needed."

63, p 3

35. "Vehicular mobility within cities is more affected by the level of fire encountered than in the field.

"In general, combat in cities places lesser requirements on vehicle range on endurance than does combat in the field, thus offering opportunities for trading these performance attributes for others, such as agility, maneuverability armor and armament."

69, p 2

A.6 GAPS

1. "The crew tolerance to shock and vibrations has, generally, been defined by several different criteria, such as rms g, maximum tolerable g, and absorbed power as measured in watts...Unfortunately, there appears to be very little correlation between any of these measures...and mobility performance (movement) of the tank."

1, p 3

2. "Conclusions...

(1) The magnitude of the overall land mobility technology development program is small in contrast to total DOD costs related to land mobility.

(2) The limited DOD resources available for land mobility research and development must be applied to problems of uniquely military concern; commercial resources must be relied upon for technological development in areas of mutual commercial and military interest.

(3) The salient deficiency in the land mobility technology base is the absence of a credible, comprehensive methodology for the characterization, measurement, and prediction of system performance and effectiveness.

(4) There is a pressing need for increased development and testing of experimental prototypes to...reduce the lead time and risk of system development in areas of uniquely military interest...

(5) The composition of the current DOD land mobility technology program is generally consistent with existing military requirements. Reprogramming and/or additional funds are needed, however, to (a) properly focus fragmented activities...(b) provide resources to assure the attainment of critical technology goals in high priority program areas..."

5, p 5-6

3. "In the absence of a validated methodology for evaluating land mobility...decisions have in the past been made on the basis of ad hoc studies and analyses in which mobility aspects have not been adequately addressed."

5, p 23

4. "...the ASAP Study Proposal...contains the following problem statement:

'Army methodology for defining requirements and promoting new advances in combat vehicles is not integrated and requires examination. The resultant effect is that advances, both in concepts and components, are not available on which to base new combat vehicle design'."

6, p 4

5. "Mobility, only one aspect of combat performance, cannot be divorced from armor protection, range, fuel consumption, crew size, logistical supply and so forth...hovering over all such considerations are the nature of the enemy threat and the manner in which the combat vehicle will be use tactically...Life cycle costs must be taken into account...inadequate reliability and maintainability are factors that may militate against the choice of otherwise desirable mobility hardware..."

6, p 9

6. "...it is unrealistic to expect that the overall success of a new design can be judged quantitatively in terms of an established index of merit; or even a small number of such indices...Many sub-elements of the total mobility problem can be studied effectively through simulation and experimentation, leading to valuable methods for appraising the extent to which new concepts and designs will fulfill certain functional requirements. Establishing a standard procedure for integrating these inputs into an overall index of merit, however, inevitably involves so many assumptions and approximations that the final result will be unconvincing at best, and possibly even misleading."

6, p 9, 10

7. "Many of the predictive methods now being used have not been subjected to experimental verification, and cohesive plans for doing so are not in evidence."

6, p 15

8. "...validation of simulation models is only an incidental activity to other missions and is not separately called out and funded."

6, p 26

9. "...Apparently, a significant degradation target acquisition capabilities occurs in buttoned up moving tanks...on two occasions I observed a defending tank engaging three or four attacking tanks from the flank without the attacking tanks returning fire. On a task or function basis, it may be asking too much for the tank commander, who is the only individual with a 360^o field of view, to be a '360^o observer'."

7, p 2, 3

10. "...a recent AMSAA analysis using their AMSWAG model...looked at the impact on attacker and defender survivability as the formers 'speed' was varied...in two ways...attacking vehicles...move faster...

Speeds and halts were selected to hold 'total' engagement time constant...faster speeds were used...acompanied by 'normal' halts... Both XM-1 and M60A3 were evaluated in the attacking role...results indicate some improvement in attackers survivability...the advantages accrued appear fairly marginal...doubtful that the improvements... justify much in the way of additional costs...this kind of small unit analysis is addressing only part of the potential advantage of greater vehicle speed. The other aspect is the ability of small units to move on the battlefield--i.e. timely reinforcement to meet rapidly developing threat situations. For this, one obviously needs a model of at least division scope.

10, p 1, 2

11. "Operational effectiveness should be distinguished from performance, which is the degree to which a particular alternative accomplishes its assigned tasks. Operational effectiveness is a force attribute; performance is an attribute of a particular alternative. TRADOC in a COEA, is concerned primarily with operational effectiveness. A new alternative may possess a significant increase in performance (velocity outputs from AMC '71) but its introduction into the force might not produce a combat effectiveness improvement in the force. In essence, AMSAA and ARCOM have a definate need for AMC '71 while TRADOC (user) cannot directly implement AMC '71 output results."

14, p 2, 3

12. "Recently, MG Tarpley asked AMC for analytical support for the MICV Special Study Group (MSSG). We were able to provide part of the support he needs, but can't help in the most important area--the study of the relationship between superior mobility of the MICV, and the combat effectiveness of the vehicle. In reviewing ways to offer analytical support, I became concerned that the Army does not seem to have a methodology (or the analytical tools) to adequately study this important relationship...I have asked AMSAA to begin working to develop the needed methodology. This is an extremely difficult area and I've been warned not to be overly optimistic.

15, p 1

13. "Part of our problems arise, I feel, from the tendency to equate high top speed with high levels of mobility/agility. I would even argue that the search for higher top speeds in combat vehicles has served primarily to limit true mobility/agility, and that our current ROC's are even written in such a manner that the designers are constrained to produce vehicles with limited mobility/agility characteristics in order to meet them. For example, top speed requires a specific transmission design which serves to limit low speed performance; and this low end performance, especially acceleration, is where I think we really need improvement to achieve true hypermobility/agility..."

17, p 2

14. "As we understand the present U.S. design concept for advanced tank fire control systems, it is based on stabilizing the gun and not the sight (with the gun slaved to the sight). Put another way, we do not take full advantage of the complete concept of the disturbed reticle."

19, p 12

15. "Mr. Fredericksen, DDRE, in commenting on the XM1 COEA Study Plan on 20 Dec 74, brought up the mobility pay-off...Both GAO, in its XM1 Tank System Staff Study (Feb 74) and Senator Eagleton, in his letter to GAO (19 Dec 74) asked about the mobility/protection tradeoff."

21, Incl f, p 1

16. "...we identified two basic questions which we feel need to be answered...Is the current AMSAA mobility study the Army effort to answer Mr. Fredericksen, Mr. Eagleton, and the GAO?...Who will see to it that the Army's effort to answer these questions is adequate and timely?...This Project Office does not have the resources to solve the problem. However, we currently feel the pressure of GAO inquiries into this matter and are having difficulty describing how the Army plans to solve the problem."

21, Incl e, p 1, 2

17. "Recent questions by Senator Eagleton have highlighted the need for a definitive study to assess the trade-offs between agility and heavy armor in terms of survivability. Issues related to these aspects of the design of tanks and other fighting vehicles arise in both the MICV and XM1 development programs. While there are several efforts underway in TRADOC, AMC, and DA to illuminate the problem and to provide answers, this headquarters is concerned that we have not identified a plan of action that incorporates this work into a coherent answer to the mobility/agility protection question, not only for Senator Eagleton, but for the improved design of combat vehicles as well."

21, Incl c, p 1

18. "It has been suggested by DCSOPS and MG Starry that the Future Armor Component Steering Group address the issue and develop a plan for resolving the question as outlined by USAMC...it will tend to bring the user community 'on board' with USAMC in their assessments of the trade-offs between agility and survivability...this is an old problem which has not been resolved due to the lack of an agreed approach and methodology."

21, Incl b, p 1

19. "The US Army is concerned with question: What do obstacles have to do with winning or losing battles?...the paper notes that the measurement of obstacle effectiveness has remained primitive and produced unconvincing results. Part of the difficulty is traced to limitations in the representation and interpretation of obstacle-free combat..."

23, Rpt Doc Page

20. "The theoretical and empirical evidence of obstacle-free combat indicates that US forces have some additional battlefield requirements. This result provides some theoretical evidence, far short of actual proof, on behalf of obstacles...In reality, we know so little about combat with or without obstacles that it seems impossible to compensate for combat's complexities by pre- or post-multiplication."

23, p 31, 32

21. "Measuring obstacle effectiveness has remained a primitive art still based on relatively weak theoretical and empirical grounds. The empirical foundations are the weaker of the two...Most of what obstacle analysts usually cite as obstacle effects have not yet been related to the assigned tasks and missions of a force as a whole...the most frequently cited historical examples of obstacle effectiveness are cases where a defender had months to prepare and devoted as much as 720 man-years of effort per kilometer of front to obstacle and fortification development..."

23, p 46

22. "Much of the weakness in measuring obstacle effectiveness is attributable to often-forgotten, little-discussed weaknesses in the representations of obstacle-free combat..."

23, p 46

23. "There is an urgent need for additional human engineering data and their analysis."

47, p 43

24. "Another reaction to the existence of alternative designs are general arguments about their 'firepower', 'mobility' and 'protection'. Invoking these three traditional concepts helps to clarify discussions by emphasizing three major facets of tank design but is of little help in evaluating tanks as a whole. For one thing, 'firepower', 'mobility' and 'protection' do not lend themselves to a precise definition."

57, p 132

25. "Special situations within the urban environment place either constraints or new requirements on the mobility function...may not be met by vehicles and equipment in the current inventories, and thus identify gaps in requirements for or knowledge of equipment performance in the urban environment."

69, p 1

Appendix B

CROSS-INDEXED REFERENCE FILE

TABLE OF CONTENTS

Appendix B

CROSS-INDEXED REFERENCE FILE

B.1 NUMERICAL LISTING OF LITERATURE SEARCH CITATIONS*

NUMBER	CITATION
1	"A Human Factors Review of Tactical Mobility Combat Agility for the M60 Series Tank." A. J. Eckles, III. Human Engineering Laboratory, TN 8-72. June 1972. 9 p. refs. LIMITED.
2	"Mobility and Survival." Bryant Dunetz & Ceslovas Masaitis (USA Ballistic Research Labs.) January - February 1975.
3	"The Effects of Increased Target Mobility/Agility on Gunners' Performance." A Field Study conducted jointly by the ARSV Task Force and The Human Engineering Laboratory. August 1974. (Outline Test Plan.) 10 p.
4	HELAST II—A Field Study of the Effects of Mobility/Agility on Target Presentation and Defender Reaction. A. J. Eckles, III, T. A. Garry, Wm. C. Mullen & H. Aschenbrenner. The Human Engineering Laboratory, TM-12-73. July 1973. 61 p.
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* Coded in two classes:
1 - Contributory to linkages (complete or partial)
2 - Non-contributory but useful background or data.
Circled numbers belong to Class 1.

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ANNEX C

SYNOPSIS OF ON-GOING AND PLANNED INVESTIGATIONS, AND RECENT TEST PROGRAMS

ON-GOING AND PLANNED INVESTIGATIONS

1. Armored Combat Vehicle Technology Program (ACVTP): The ACVTP consists of three basic parts which can be roughly termed as STAGS/HIMAG IIA, HIMAG A/B and HSTV-L, each which is discussed below.

a. STAGS/HIMAG IIA: This portion, now complete, gathered basic performance data on a number of "high mobility" vehicles (e.g., S-Tank, ARSV and El Camino truck) and can be considered as having served as a training exercise for future investigations. Major conclusions were:

- Maneuvers must not reduce vehicle speed
- A slow,less agile vehicle (which must reduce speed to maneuver) should employ 'dash' - except for a head-on course
- All vehicles should maneuver when approaching head-on
- The long sine is superior to free play (as a maneuver)

b. HIMAG A/B: This portion of the program will examine a "variable design" test rig, first without and then with a turret/gun combination (which in itself will incorporate a developmental 75mm KE gun and a variable-capability fire control system). Stated HIMAG A/B objectives are:

- To provide data for cost effectiveness trade-off analyses needed to develop future combat vehicle requirements
- To facilitate the evaluation of the value of differing performance levels in combat vehicles

- To integrate advanced technology component concepts into a test bed in order to demonstrate component feasibility
- To provide a base of proven, advanced technology for armored vehicles of the 1990's.

Chassis testing will commence in the Fall of 1977. The full-up chassis/turret system is presently scheduled for testing from June 1978 through September 1979. Emphasis as shown in the objectives above will focus on technology and performance. Of particular interest is the capability to vary engine power and chassis weight to achieve HP/ton ratios of 20:1 through 60:1.

c. <u>HSTV-L (High Survivability Test Vehicle (Lightweight)</u>: HSTV-L objectives are to examine:

- Innovative system designs and integration
- The feasibility of an externally mounted KE gun.

The HSTV-L design will be competitively selected (AAI and PACCAR bidding), with delivery and test scheduled for 1979. The vehicle will be lighter than the HIMAG rig (16-18.5 tons vs 27-42 tons), and will incorporate a CBR overpressure system. Swim capability and air transportability will also be examined.

Of particular interest in terms of mobility are:

- The trade-offs between mobility and armor/protection which must be made in the light vehicle class, and
- The planned effort to include ACVTP data in force-on-force simulations and analysis.

2. <u>FRG Mobility Program</u>: The FRG mobility program is examining the questions of armor vs firepower and tank mobility using a dual gun (fixed), low silhouette (no turret) 35-40 ton class armored vehicle. Work has been done using serpentine evasive maneuvers and is now examining the ability to detect a threat while on the move as a part

of the overall question of protection provided by mobility. Herr Stark (FRG MOD), Program Director has proposed a joint venture with the US Army to examine tank performance and effectiveness in defense, offense and delay scenarios and missions, and specifically to address availability in time and distance, time-to-hit, and hits-to-kill. The Army has responded expressing interest. As of the date of this report, however, the FRG has not replied.

3. BRL: BRL is continuing its analysis of STAGS test data to include comparison with model results. Future work will consist of updating current interim reports related to mobility work, continuation of vulnerability/survivability trade-off studies, development of a one-on-one stochastic combat model, and an effort to describe various target maneuvers in statistical terms for which adequate test data is now considered to be available. While not funded, additional work on fire control capabilities is an area of interest.

4. CACDA: CACDA is implementing a model improvement program (a two to three year effort) which as far as mobility is concerned is concentrating on the improvement of CARMONETTE by adding the "fine grain" now available in DYNTACS. CARMONETTE will then become the primary battalion level simulation and will reside at both CACDA and TRASANA. By the end of 1977, CARMONETTE will be used to evaluate the new heavy division organization. In addition to the DYNTACS/CARMONETTE logic effort, CACDA has a continuing program on-going with Defense Mapping Agency to increase the terrain selection available as model input.

5. AMSAA: AMSAA continues to be involved in the XM1, HIMAG and HSTV-L programs and is working with TARADCOM to improve modeling of automotive performance as it relates to acceleration/agility. The XM1 Materiel Need is being examined with a view towards reflecting a fire control requirement in terms of target motion, expressed as varying accelerations.

RECENT TEST PROGRAMS

1. In an attempt to better understand the many recent test programs, a set of tables was developed which displays the type of data collected, target vehicles and firing platforms used, tracking method, and target vehicle maneuvers employed. This display was derived from inputs provided by the one-on-one work group and is obviously not definitive in that detailed test plans and actual results have not been examined. Nevertheless, several observations (if not conclusions) may be made. Table C-1 lists the basic data types taken in each of the five completed tests shown. Note that the data types are different in each case, the differences showing in more detail in the "Aiming/Tracking Data" section of Table C-3. In like manner, a listing of vehicle/weapon systems used as targets and/or firing platforms is shown at Table C-2. Again a "shotgun pattern" is apparent with the exception of the relatively common use of the M60A1 in both categories. Table C-3 brings together target maneuvers, tracking method and data taken. Instrumentation methods, while not shown, could introduce another significant variable.

2. From these tables taken together, the following observations are made:

- Data correlation between tests is/will be difficult, which will probably result in careful caveating of any generalized conclusions.
- Data is principally taken from the viewpoint of the firing vehicle. Mobility aspects then become a matter of threat system degradation rather than a positive look at mobility. (This is not necessarily bad, particulary in one-on-one examinations, but may tend to obscure mobility aspects.)
- The STAGS/HIMAG IIA/HIMAG A/B sequencing appears to present the best possibility for correlation and aggregation under controlled conditions.

- The testing program shown is a first step. Not enough is known by the writer of the details of CHINESE EYE, but this test type would appear to be the graduation exercise.

- The emphasis is clearly on the "survive" mission. Examination of the "defeat" mission is apparently left to analytical work insofar as mobility is concerned.

TABLE C-1. MOBILITY RELATED DATA OBTAINED FROM TEST/EXPERIMENT PROGRAMS

DATA	TEST: STAGS	ATMT	ITV	HIMAG IIA	HELAST II
1. Aiming/tracking error as function of apparent velocity, acceleration and maneuver.	X				
2. Miss distance.	X				
3. Aiming/tracking error as a function of range, maneuver and target type.		X			
4. Effect of breaking line-of-sight.		X			
5. Aiming/tracking error as a function of range, cant, maneuver and time of day.			X		
6. Probability and time of detection as a function of target mobility and range.					X
7. Nr rounds fired as a function of target mobility.					X
8. Aim point at time of trigger pull.					X
9. Aiming/tracking error as a function of velocity, acceleration and range.				X	

TABLE C-2. VEHICLE REPRESENTATION IN
TEST/EXPERIMENT PROGRAMS

TEST VEHICLE/WPN	AS TARGET								AS FIRING VEHICLE							
	STAGS	ATMT	ITV	HIMAG IIA	HIMAG A/B (1978)	HSTV-L (1979)	HELAST II	Hardison	STAGS	ATMT	ITV	HIMAG IIA	HIMAG A/B	HSTV-L	HELAST II	Hardison
M60A1	X	X	X				X	*	X	X		X	X		X	X
M60A3																X
M60A2 (Shillelagh)										X						
XM1													X			X
M551 (Shillelagh)										X						
S Tank	X								X							
T62													X			
ARSV(XM800)	X	X														
M113	X						X									
M113 (2 engine)	X															
RVT (FRG)	X															
TOW (Ground)									X	X						X
M113/TOW											X	X				
ITV variants											X					
DRAGON										X						
El Camino				X												
Twister (XM808)	X	X														
XM300 Test Bed							X									
ATAADS													X			
HIMAG Test Rig					X											
HSTV-L						X										
Leopard II																X

*Light (spot) moving in circular pattern to give sine perception.

TABLE C-3. TARGET MANEUVERS AND TRACKING METHODS IN TEST/EXPERIMENT PROGRAMS

	TARGET MANEUVERS							TRACKING			AIMING/TRACKING DATA AS A FUNCTION OF ...						
TEST/EXPERIMENT	Sine Variants	Dash	Free Play	Rapid advance	Tactical routes	Turns/swerves	Circular	S Tank w/lead	M60A1 w/lead	M60A1 w/o lead	Velocity	Acceleration	Maneuver	Target Type	Cant	Time of day	Range
STAGS	X	X	X					X	X		X	X	X				
ATMT	X					X				X			X	X			X
ITV	X			X									X		X	X	X
HIMAG IIA	X								X	X	X	X					X
HELAST II					X					X							
Hardison						X	X		X	+		X					
TETAM			X		X												
CHINESE EYE (UK)			X		X												
HIMAG A/B	X*	X*	X*								X*	X*	X*				
High Mobility Tank (FRG)	X																
HSTV-L **																	

*Not firm.
**Unknown.
+XM1/M60A3 w/computed lead.
X Sine perception.

Appendix D

WORKING MEETING REPORT OF PROCEEDINGS (EXECUTIVE SUMMARY)

1. This report presents a record of the proceedings of a working meeting held at the National War College, Fort McNair, Washington, D. C. on 26, 27 and 28 July 1977 under the sponsorship of the Deputy Undersecretary of the Army (Operations Research), Mr. David C. Hardison. The objective of this meeting was to develop a better understanding of the quantitative and qualitative value of tactical mobility, with emphasis on the mobility of firepower as it pertains to ground combat vehicles. The agenda and list of participants are found at Annexes C1 and C2 respectively (omitted).

2. The meeting was structured around three working groups oriented on the individual vehicle in one-on-one/n combat, the small tactical unit, and the combined arms force (large unit) respectively. Following an opening general session, these groups, in separate working sessions, developed assessments which were then presented to the full group at a closing general session. As a part of its on-going mobility contract work, Science Applications, Inc. (SAI) presented to the full group at the opening session, the results of its investigations to date consisting principally of a taxonomy for structuring mobility related tasks and characteristics, and a synthesis of a literature search in the form of an analysis and a compendium of extracts, a copy of which was provided to each participant.

3. Issues (objectives) to be addressed consisted of the following:

a. How should tactical mobility be defined for an individual vehicle in one-on-one combat? (...for a small unit/combined arms force?)

b. What mobility measures of performance are appropriate for this echelon?

c. What is the relationship between mobility performance and the other performance characteristics of a fighting vehicle (small unit/combined arms force)? What trade-offs are meaningful?

d. What are appropriate measures of effectiveness for an individual vehicle in one-on-one combat (...for a small unit/combined arms force)? Can they be used as inputs for the small unit level?

e. Do transforms (models) exist for quantifying the MOEs?

f. What has been done to measure the effectiveness of tactical mobility of individual vehicles in one-on-one combat? (one on "n") (...of a small unit/combined arms force)

g. What are the data, testing, and analysis gaps?

h. What should be done to measure the effectiveness of tactical mobility of individual vehicles in one-on-one combat? (...of small units/combined arms forces)

i. How does the sum of the foregoing contribute to the meeting objective (determining the value of tactical mobility?)

3. The report follows the conference agenda in presenting the proceedings in the order shown:

- Opening session (including presentations)
- Reports developed by the separate work groups
- Closing session (including work group presentations)

An SAI developed summary of mobility related models/games, studies and tests and various presentations made to work groups (including a summary of the HIMAG program presented to the general session) are included in the annex section.

4. No analysis other than that made by the participants is presented herein. Non-substantive editing was performed in the case of presentations recorded by the stenographer during plenary sessions.

5. Major findings and observations:

a. The establishment of measures of effectiveness in the mobility area as such is not meaningful. It is the effectiveness of a system, whether an item-level system such as a tank, a small unit system, or a major force system which should be considered. Mobility is then a property of the system which will contribute to the capacity of the system to accomplish its mission.

b. Block speed is a very small multiple of movement speed. It therefore follows that qualitative changes in vehicle speed may produce a far lower change in the capacity of a system to reposition itself than might otherwise have been thought. Modeling of this block time is desirable.

c. The extent to which long range, general support artillery forces of the future require an enhanced mobility capability requires further study.

d. The vulnerability of surveillance radars requires further study.

e. Scenario coverage of the mission spectrum is inadequate. Primary emphasis to date has been on the "attack", with a small amount of work on the "defense". "Delay" and "exploitation" have been ignored.

f. Test data have been collected at a far greater rate than they have been reduced to digested information. A testing moratorium may be beneficial, during which a better understanding of data already collected can be developed. This could then lead to a more effective future testing program.

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THE QUALITATIVE AND QUANTITATIVE VALUE OF TACTICAL MOBILITY.(U)
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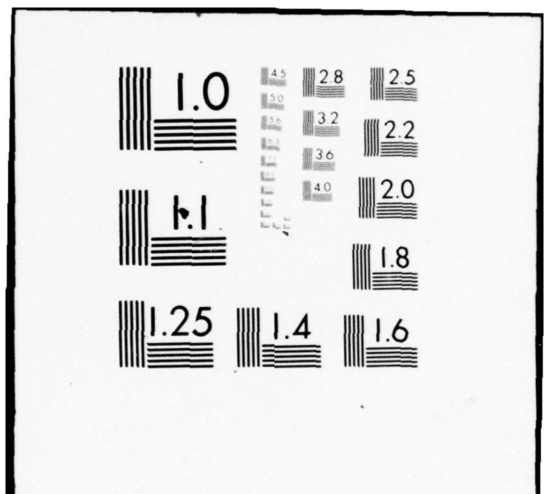

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

g. The "evade"-to-improve-survivability criterion apparently places the most stringent requirements on the vehicle designer. The contribution of mobility to survivability may not yet be well understood, however.

h. Testing, data and analysis gaps remain.

i. The translating of perceived gaps into experimental and analysis programs with resources available requires improvement.

j. A broad understanding of a force's capability to move itself, what impedes it, how changing its components will facilitate movement, and how the capability of the force to accomplish its mission changes with changes in the capabilities of individual components remains a proper objective.

Appendix E

NONLINEAR VELOCITY RELATIONSHIPS

E.1 MOVEMENT UNDER FIRE

This development is due to Tiede* and pertinent portions of the cited reference have been extracted.

> "Assume, on this basis, that one component of enemy fire is a flux that is uniformly distributed throughout the area of friendly movement and against which there is no cover. Call friendly exposure rate (hits per unit time) to this first component of enemy fire, e_1. Assume a second component, with higher peak values, that is caused primarily by enemy-observed fire weapons and to which friendly exposure occurs only during periods of actual movement. Call exposure rate to this second component, e_2. Experience indicates that maneuver elements (infantry and armor) move by bounds in such an environment to reduce exposure rate to the second type of fire. This is accomplished by moving at high speed (to increase enemy aiming error) in short spurts (to take advantage of enemy reaction time) to successive positions that afford cover and concealment (minimum exposure rate). Further simplification can be made in this model by assuming that cover and concealment against e_2 are uniformly and widely distributed so that the duration τ of the movement spurts is an independent variable against which exposure can be optimized. Under these conditions, movement can be represented as a series of ramp functions, as depicted in Figure 2-2, that are generated by a series of moves at maximum speed r, and successive moves are interspersed with halts of duration t_s. From Figure E-1, it is clear that the aggregate distance covered, s, is given by
>
> $$s = r \sum_{1}^{n} \tau \tag{4}$$
>
> where n is the number of moves, and the average velocity v by
>
> $$v = \frac{s}{t} = \frac{r \sum_{1}^{n} \tau}{t}. \tag{5}$$
>
> Applying the simplification of uniform time intervals, it is noted that each bound covers distance $r\tau$, and that the number n of bounds required to cover distance s is
>
> $$n = \frac{s}{r\tau} \tag{6}$$

---

*Tiede, R. V., A FORMULATION OF GROUND COMBAT MISSIONS IN MATHEMATICAL PROGRAMMING FORM, Research Analysis Corp., Technical Paper RAC-TP-265, July 1967.

and that

$$v = \frac{r\tau}{t_s + \tau} \tag{7}$$

and

$$t = \frac{s}{r\tau}(t_s + \tau). \tag{8}$$

A cost function associated with such a movement can be defined. If cost is measured in casualties, exposure becomes a measure of cost. Assume that the number of hits, and therefore exposure, resulting from direct fire on a target that suddenly springs up and moves has a time variation of the form illustrated in Figure E-2, Exposure starts at zero because of enemy reaction time and rises rapidly as aiming error decreases but saturates at some value E_2 because of lead error and irreducible aiming error. Such a function can be approximated by the complement of the error function, i.e.,

$$\epsilon_2 = E_2(1 - e^{-h^2\tau^2}) \tag{9}$$

where h is a constant equal to the reciprocal of twice the variance of the error distribution. If the uniform flux of enemy indirect fire is superimposed, we add constant-exposure component $\epsilon_1 = E_1$, and the total exposure as a function of times looks like Figure E-3, Summing over the exposure times gives us the total exposure ϵ which is the total c for this example:

$$\epsilon = \int_0^t E_1\,dt + \sum_{i=1}^{n}\int_0^{\tau_i} E_2\left(1 - e^{-h^2\tau_i^2}\right)d\tau_i. \tag{10}$$

This general expression can be readily reduced for the simplifying assumptions of Eqs 6, 7, and 8 to

$$\epsilon = E_1 t + \frac{sE_2}{r} - \frac{sE_2}{r\tau}\int_0^{\tau} e^{-h^2\tau^2}\,d\tau. \tag{11}$$

Applying Eq 8 gives

$$\epsilon = \frac{s}{r}\left[E_1 + \frac{E_1 t_s}{\tau} + E_2 - \frac{E_2}{\tau}\int_0^{\tau} e^{-h^2\tau^2}\,d\tau\right]. \tag{12}$$

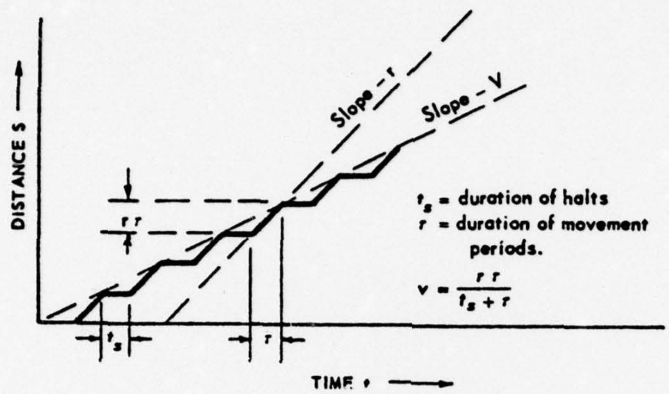

Figure E-1. Movement by Bounds

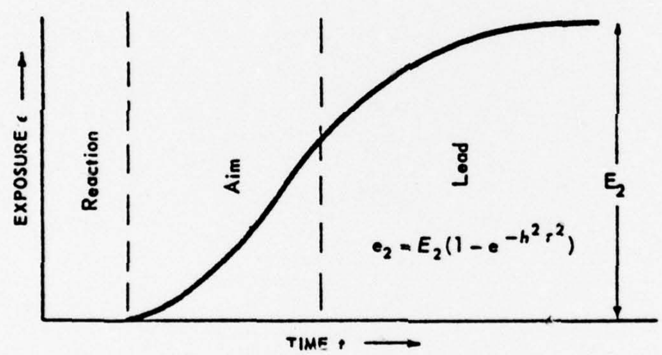

Figure E-2. Time Variation of Exposure to Direct Fire

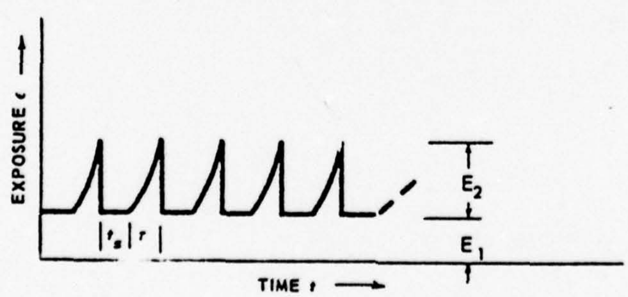

Figure E-3. Time Variation of Total Exposure

One other constraint must be applied before attempting to optimize this cost function. In Figure E-3 it can be seen that cost, as defined for this analysis, is essentially the area under the curve. This area can be reduced by reducing t_s. Bearing in mind that the cusps corresponding to time intervals τ are initial segments of the curve in Figure E-3, the area can further be reduced by shortening the duration of each movement time τ. This in turn necessitates increasing the number of moves. In the limit, there would be an infinity of such movement bounds, each of which would have a duration approaching zero. But there are real-world constraints that prevent optimization in this way. Not the least of these is that the duration of each static period, t_s, must equal or exceed some finite value if relation 9 is to hold. That is, the exposure to the observed fire component does not return to zero if the direct fire weapons have not returned to a static state. The further assumption is made that t_s has been reduced to the critical finite value required to ensure that $e_2 = 0$ at $\tau = 0$. This requires that there be a finite number of moves of duration τ.

If the derivative of the cost function defined by relation 12 is taken with respect to τ and the result is set equal to zero, the minimum cost relation becomes

$$\frac{E_1}{E_2} t_s = \int_0^{\tau} e^{-h^2 \tau^2} d\tau - \tau e^{-h^2 \tau^2} \tag{13}$$

Making the usual series expansion of the error function, collecting terms, and simplifying yields the following relation, which is easier to handle for approximate calculations:

$$\frac{E_1}{E_2} t_s = \tau \left[2/3\, h^2 \tau^2 - 4/5 \left(\frac{h^2 \tau^2}{2!} \right)^2 + 6/7 \left(\frac{h^2 \tau^2}{3!} \right)^3 - \ldots \right]. \tag{14}$$

If a suitable range of values is selected for the parameters E_1, E_2, t_s, and h (which in turn fixes the standard deviation σ, since $h^2 = 1/2\sigma^2$), relation 14 can be used to calculate values of τ corresponding to minimum cost. Then relation 7 is used to calculate the corresponding ratios of velocity (at minimum cost) under fire, V_{opt}, to velocity r, which was assumed to be maximum velocity with no enemy opposition. Figure E-4 shows how this ratio varies over a range of the other parameters.

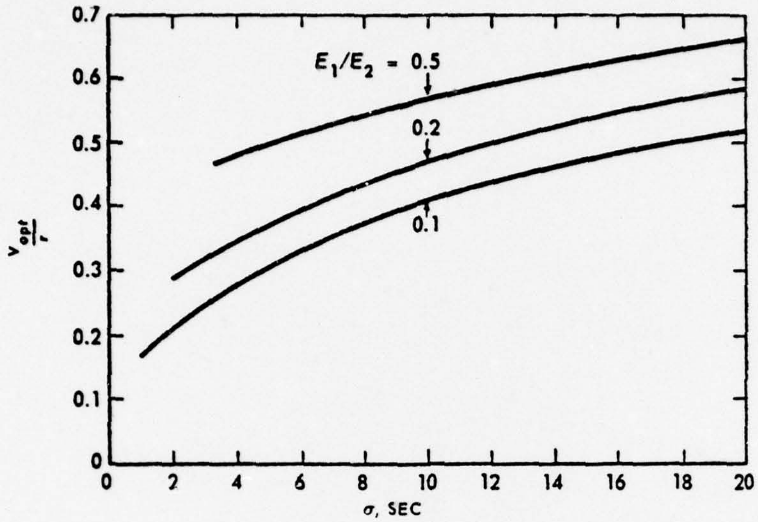

Figure E-4. Variation in Optimum Velocity Ratio Resulting from Enemy Fire

As expected, the above optimum rate-of-advance ratio increases as the observed fire exposure factor E_2 is reduced. This checks with reality; certainly the enemy has less control of the area through which friendly forces are moving if the intensity of enemy direct fire is reduced--or if friendly forces can provide armored protection so that they are in effect covered while moving. The ratio also increases as the σ of the inverse error function in relation 9 increases. This standard deviation is of course a measure of enemy-reaction time to friendly movement, and the more slowly the enemy reacts, the more rapidly friendly forces can advance.

Relations 13 and 14 reveal that the duration τ of the movement bounds becomes very large, and hence the optimum rate-of-advance ratio approaches unity, for either of two conditions:

(a) E_2 becomes very small. This case has already been discussed.

(b) E_1 becomes very large. This would imply that a high density of enemy-unobserved fire does not add to his control over area. Within the assumptions of this problem, this is true because it is known that a unit faced with the problem of moving through such a concentration of presumably unobserved fire does one of three things: moves through the fire at maximum velocity, waits until the fire lifts, or moves around the concentration. The terms of the analysis

above permit description of only the first of the three alternatives, since it has been assumed that the unobserved fire flux is unbounded in space and time. The expression does give the right answer for these assumptions. In an actual case, such fires are of course bounded both in space and time, which permits one to wait it out or skirt the fire. Either of these alternatives slows the rate of advance, but the model would have to be extended to include them.

E.2 RELATIONSHIP OF SUPPORT MOBILITY TO FORCE MOBILITY

The purpose of this development is to provide yet another illustration of the hypothesis that there is not a simple linear relationship between the mobility of individual elements on the battlefield and the mobility of the force as a whole. This simplistic model is limited to a consideration of the relationship between the over-the-ground speed of certain support elements and the rate of movement of the force as a whole under some very simplifying assumptions.

DEFINITIONS

Let:

V_m be the average speed at which the FEBA is moving.

V_s be the average speed at which the support elements need to move.

R be the maximum distance that the support elements can be separated from the FEBA and still perform their primary mission.

T_s be the time required for the support element to "march order".

T_f be the time required for the support element to become operational once it has stopped moving.

S_a be support element a.

S_b be support element b.

ASSUMPTIONS

- The rate at which the FEBA is moving is a measure of force mobility.
- That the level of combat is such that the support of either S_a or S_b is required to maintain the rate of movement of the FEBA at value V_m.
- That S_a and S_b displace to follow the FEBA according to the following algorithm:
  - S_a cannot initiate displacement (march order) until S_b is operational in its new position.
  - S_b becomes operational at precisely the instant the FEBA is at distance R from S_a.
  - S_a cannot displace farther forward than the FEBA.
  - When S_a is operational in its new position, S_b displaces according to the same rules.

It will be recognized that the above procedures and constraints resemble the problem of providing continuous fire support to moving maneuver elements where the fire support means have a maximum effective range. They also resemble the problem of exercising command from a command and communications center where the maximum effective communication range to the moving forward elements is R and command cannot be exercised (no effective communication) when the command post is moving so that it displaces by echelon. Finally, they are also analogous to the problem of providing service support where service support installations (e.g., supply points) cannot provide adequate support when separated from front line supported units by more than some distance. The complicating factors introduced by terrain, to include movement routes and siting problems have obviously not been considered.

Figure E-5 is a representation of the time and space factors involved in developing an expression of the support element speed, V_s, required for various values of V_m, R, T_f, and T_s. Time t = 0 represents the time at which S_b is ready to assume support of the maneuver units on the FEBA. The positions of the FEBA, S_a, and S_b at t = 0 are indicated. Since S_b was at the FEBA when it stopped to go into its t = 0 position (Assumption 3c), the FEBA has moved a distance of $V_m T_f$ since S_b stopped to go into position. At time t = T_s, S_a is still at its t = 0 position but has completed its march preparation time and is initiating movement. The FEBA has moved forward a distance of $V_m T_s$ from its t = 0 location. At some as yet undetermined time, t = t_1, S_a moving at its higher movement rate of V_s has caught up with the FEBA so that S_a and the FEBA are colocated at time t = t_1 as shown. At time t = $t_1 + T_f$, S_a is still at its t = t_1 position but is now ready to assume support of the FEBA; the FEBA is now located a distance of $V_m T_f$ forward of its t = t_1 location and (Assumption 3b) precisely distance R forward of its t = 0 location.

From Figure 1 we can write two relationships:

$$R = 2 V_m T_f + V_m t_1 \tag{1}$$

$$V_s = \frac{R + V_m (t_1 + T_f)}{t_1 - T_s} \tag{2}$$

Substituting for t_1 from (1) and simplifying:

$$V_s = \frac{2R - T_f V_m}{R/V_m - 2 T_f - T_s} \tag{3}$$

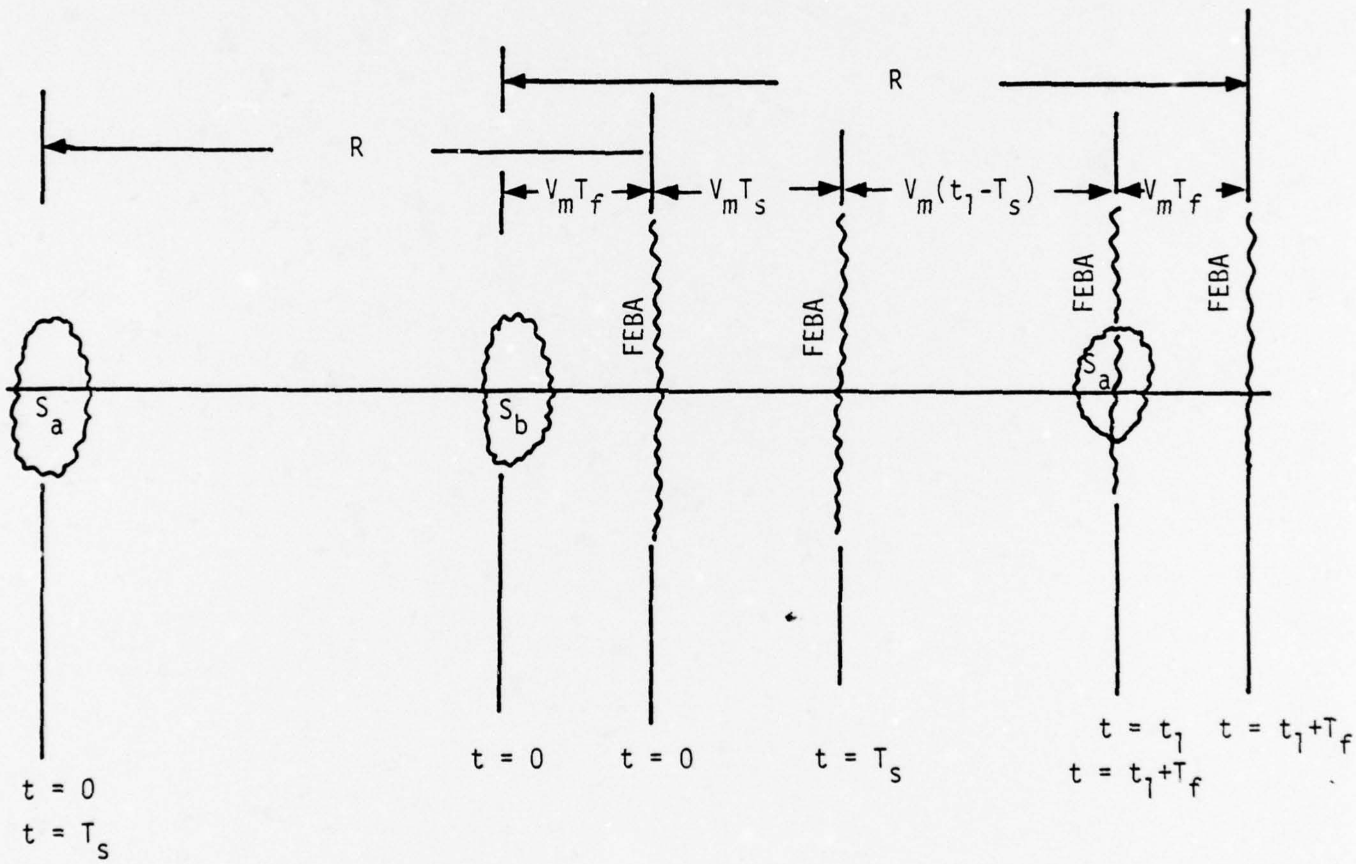

Figure E-5. Successive Locations of Maneuver and Support Elements

Relation (3) can be used to plot the variation of the required support element speed with parametric variation in V_m, R, or T_f and T_s. This is done in Figures E-6a, b, and c. It will be noted (Figure E-6a) that V_s is very sensitive to changes in V_m. For the values of R (10 kilometers) and $T_f = T_s$ (1/4 hour) chosen, V_s becomes infinite when V_m reaches a speed of 13 1/3 kilometers/hour.

The variation of V_s to changes in support range, R, is great over a small region as shown in Figure E-6b. With the FEBA moving at a rate of 4 kilometers per hour and T_f and T_s set at 1/4 hour, V_s changes from infinity at an R = 3 kilometers down to 12 kilometers/hour at R = 8 kilometers. Increasing the support range beyond this range has little effect on the required support element speed.

Figure E-6c shows how V_s changes with changes in the march order and fire preparation delay times (presumed equal for this presentation). As expected the required support element speed again reaches infinity for some value of delay; for the values chosen in this figure, V_s becomes infinite when T_f and T_s = 5/6 hour.

There is probably very little in such a development that is either new or relevant to support operations in general. Nevertheless, it does show that when support is provided subject to the assumptions made earlier, there is some speed of movement of the maneuver elements in contact which requires that the support move at a rate not supportable by land movement--or a change in the algorithms for providing that support is indicated. There is no question that the stated assumptions break down for direct artillery support because it has been shown that when maneuver units in contact are able to move at rates much beyond 2 or 3 kilometers/hour they do not require continuous artillery support. On the other hand, the same consideration indicates why command posts need to be airborne if they are to communicate with rapidly moving front line elements. Figure E-6b also indicates that, given a rate of movement of the maneuver elements

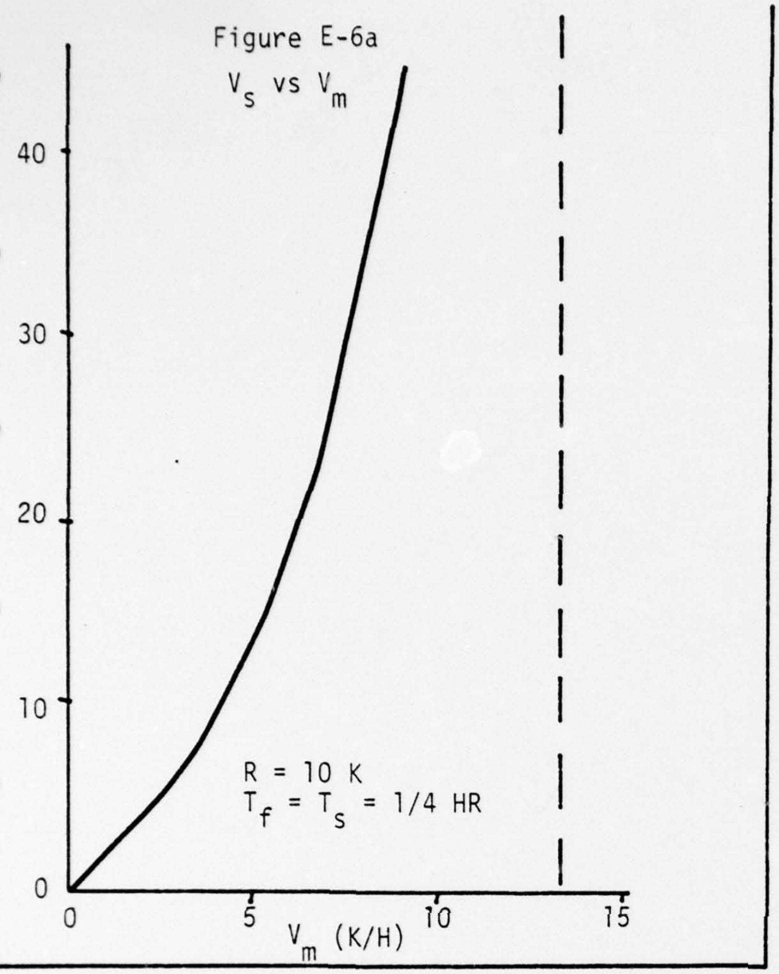
Figure E-6a
V_s vs V_m
R = 10 K
$T_f = T_s = 1/4$ HR
V_m (K/H)
0
5
10
15
10
20
30
40

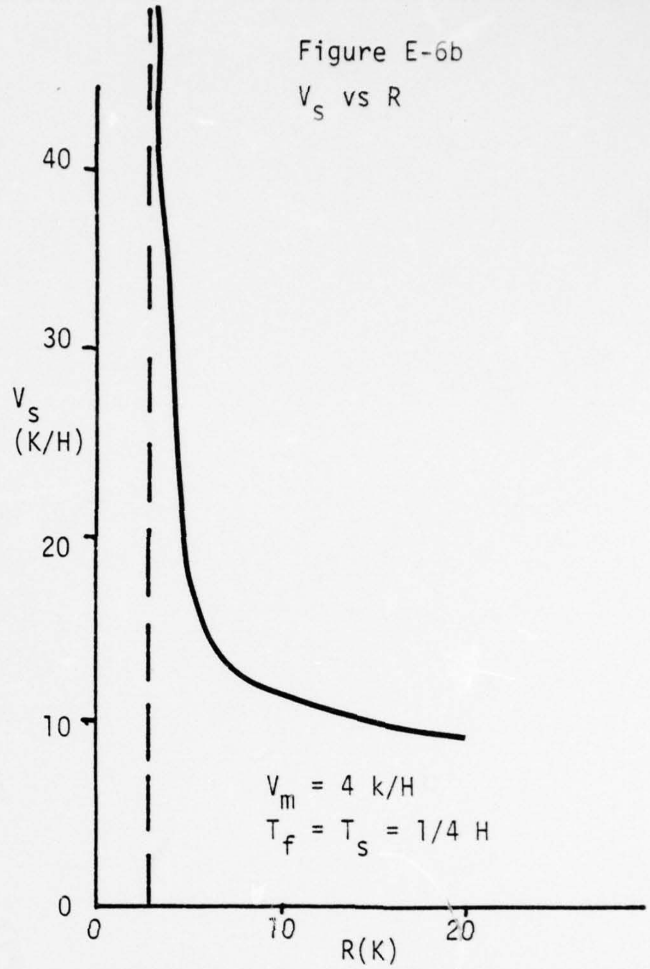
Figure E-6b
V_s vs R
V_s (K/H)
$V_m = 4$ k/H
$T_f = T_s = 1/4$ H
R(K)
0
10
20
30
40

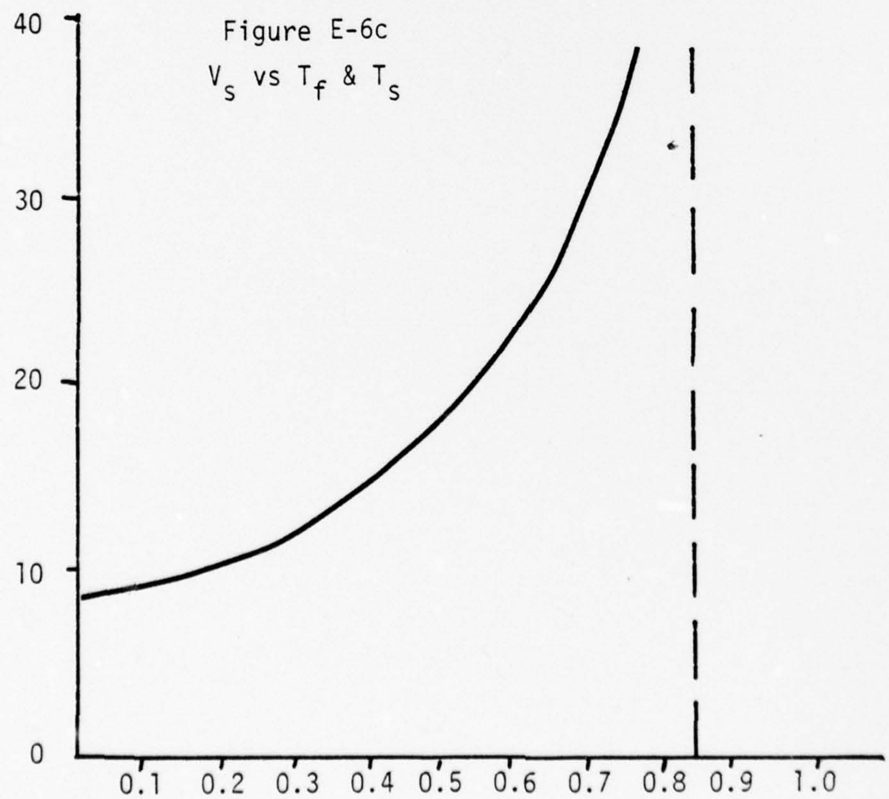
Figure E-6c
V_s vs T_f & T_s
0
10
20
30
40
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

that must be supported, there is a range of distance of effective support below which it is probably cheaper to buy support by increasing the support range (weapon, communication, or more supply vehicles) and above which it is cheaper to buy it by increasing the movement of the support element.

At Figure E-7 is a nomographic solution to Equation 3 from which similar figures may readily be developed for other values of the parameters.

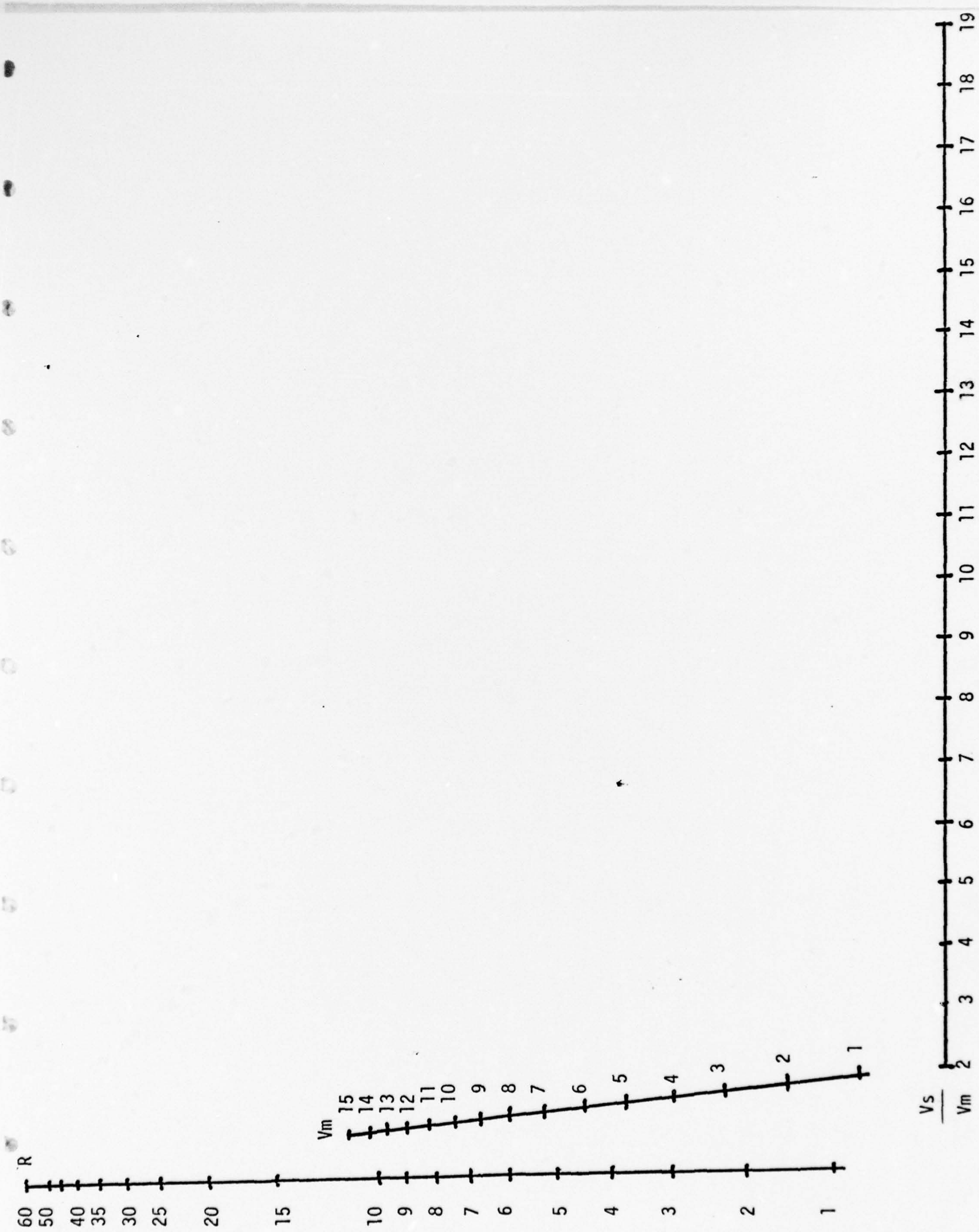

Figure 2-8. A Nomographic Solution to the Relationship Between FEBA Movement Rate, Support Vehicle Speed, Maximum Support Range, and March Order and Set-Up Time

Appendix F

ANALYSIS AND SYNTHESIS

F.1 APPLICATION OF TAXONOMY TO LITERATURE SEARCH

This section describes how the taxonomy developed in Section 3.1 was applied to the results of the literature search described in Section 3.2. Results of the literature search were in the form of extracts. These extracts did not include raw data. They did include derived results, test plans and objectives, findings, definitions and substantive insights; in short, information which represented the reference and could best serve to aid in determining the value of its contribution to tactical mobility. Each extract was classified according to the taxonomy.

F.1.1 Independent Classification by Taxonomy Elements

The presence of the first four elements of the taxonomy were determined as a first step. It was inferred what level or levels the particular extract represented, what movement characteristics were present and what combat functions and missions were covered. It must be understood that these elements were not, in general, explicitly stated in the reference being reviewed. As an example, a phrase such as "We increased the mobility of the M60 tank and determined the effect on its survivability" raises the question: What did the author mean by increased mobility? What movement characteristics were being varied or accounted for by the test, model or analysis being described? Extracts were classified according to what they represented in the original reference. Where there was doubt as to level, movement characteristics, combat functions or missions covered by the reference, a judgment was made based on best available information. In many cases the particular element was included as having the potential for having been addressed. At this stage of the process no judgments were made regarding the value of the information. This was deferred until after it had been determined whether a valid link was

formed from movement characteristic to combat function to mission for a given level of combat. As an example, a given extract of a reference may have been classified as in Table F-1.

Table F-1

SAMPLE CLASSIFICATION 1

LEVEL	MOVEMENT CHARACTERISTICS	COMBAT FUNCTION	MISSION
1 (One-on-One)	4 (Cross Country Speed)	5 (Evade)	2 (Survive)

Another extract from the same reference may have received the classification in Table F-2.

Table F-2

SAMPLE CLASSIFICATION 2

LEVEL	MOVEMENT CHARACTERISTIC	COMBAT FUNCTION	MISSION
1 (One-on-One)	1 (Acceleration) 4 (Cross Country Speed)	6 (Move UGO*)	1 (Defeat)
*Under ground observation.			

The next step was to determine what, if any, tactical mobility links were present.

F.1.2 Integration of Elements Which Form Links

Applying the taxonomy to the extracts resulted in the identification of potential links which the particular reference did or could have addressed. To continue the above example, the sample classification in Table F-1 would not form a link. That in Table F-2 would form link 1461; cross country speed to move under ground observation to defeat for the one-on-one combat level. But two or

more extracts may have a synergistic effect. If the logical union of the two sample extract classifications is taken the classification in Table F-3 results.

Table F-3

COMBINED CLASSIFICATIONS 1 AND 2

LEVEL	MOVEMENT CHARACTERISTIC	COMBAT FUNCTION	MISSION
1	1	5	1
	4	6	2

This expanded classification now represents a more complete picture of what the reference dealt with and not only produces the 1461 link of Table F-2, but two additional links: 1152 and 1462. At this point the classification was expanded to include kind of information represented by the links and the value of that information in terms of coverage.

F.1.3 Classification by Kind of Information

Two more digits were now added to the classification according to the taxonomy. If the 1152 link was judged to cover effectiveness information it was registered as 115220; if testing information: 115241. In many cases one link represented more than one kind of information as it was dealt with in various parts of the reference document. Such cases were recorded for later analysis. If no links were formed by the logical sum of all extracts a classification for kind of information was still made but no value judgement was rendered since the scope of this research was to determine the effect of the movement characteristic on tactical mission performance. The absence of a link indicated that there was no effect measured. Yet the reference may provide kinds of informtion useful for other research. Any extract could theoretically represent a situation where all possible links were present. There are 96 direct links possible when

all levels of combat are considered. The basic thesis underlying the taxonomy is that as more links are represented in the references covering all kinds of information with a coverage evaluation indicative of thoroughness, the more the literature (and the analysis behind it) is discovering regarding the value of tactical mobility. Thus the evaluation of the link is a crucial final step in classification.

F.1.4 Classification By Value

Four levels of value were considered. If the coverage of the link by the reference was judged highly relevant and thorough it was evaluated 3; medium coverage - 2; marginal coverage - 1. If the link was potentially present but the reference did not contribute information about it (either through accident or design) it was judged a missed opportunity - 0. Thus a complete classification for a link might be registered as 1152412 indicating the influence at the one-on-one level of "acceleration" through the combat function of "evade" on the mission of "survive"; with the reference providing median coverage in the testing area concerning the impact of acceleration on survivability.

F.1.5 Evaluation of the Literature Coverage

By accumulating and sorting the results of this classification process, the coverage and potential gaps inherent in the literature could be assessed both quantitatively and qualitatively.

F.2 QUANTITATIVE RESULTS OF TAXONOMY APPLICATION

F.2.1 Total Sample

Of approximately 300 documents considered, 70 were judged as having the potential for supplying information regarding the qualitative and quantitative value of tactical mobility and were researched for classification and analysis. Those not retained may have used mobility terminology but in the main dealt with either ends of the spectrum outside the area of possible linkages, i.e., either mobility

technology which can provide inputs to the links, or combat operations dealt with in its aspects other than mobility contributions. Of the 70 documents which covered the influence of vehicular movement characteristics on tactical mission performance, 42 provided a sufficient combination within their classification to form at least one of the 96 possible direct links.

F.2.2 References Which Contained Direct Links

When all of the 42 references which contained potential links are taken together, all 96 direct, three level-1-to-2 indirect, and seven level-2-to-3 indirect links (532 combinations) are potentially present but not at the value of thorough coverage for all kinds of information. To provide a picture of how the links were covered, five value category representations were developed and an analysis was made of kind of information represented at high value.

F.2.3 Categories of Coverage According to Value of Information

The 96 direct links were distributed within 42 references by value of coverage according to the categories shown in Figure F-1.

CATEGORY 1: LINKS THAT APPEAR IN TWO OR MORE REFERENCES WITH HIGHLY RELEVANT AND THOROUGH COVERAGE.

CATEGORY 2: LINKS THAT APPEAR IN ONE REFERENCE WITH HIGHLY RELEVANT AND THOROUGH COVERAGE.

CATEGORY 3: LINKS THAT APPEAR IN ONE OR MORE REFERENCES WITH MEDIAN BUT NOT HIGHLY RELEVANT COVERAGE.

CATEGORY 4: LINKS THAT DID NOT APPEAR WITH EITHER THOROUGH OR MEDIAN COVERAGE YET HAVE A POTENTIALLY HIGH DIRECT COUPLING TO MISSION ACCOMPLISHMENT.

CATEGORY 5: LINKS NOT IN CATEGORIES 1 THROUGH 4 AND WHICH DO NOT HAVE A POTENTIALLY HIGH DIRECT COUPLING TO MISSION ACCOMPLISHMENT.

Figure F-1. Categories of Linkages According to Presence, Coverage Value, and Potential Coupling

These categories were designed to represent a progression of literature concentration on the 96 possible tactical mobility linkages. The more linkages found in category 1, the more the mobility literature is ferreting out the qualitative and quantitative value of tactical mobility. Categories 2 and especially 3 represent room for improvement. Categories 4 and 5 are gaps or links not sufficiently covered in the literature. Of these latter two categories, category 4 included those links judged to be of the highest potential for mission influence and as such are priority areas for investigation. Tables F-4, F-5, F-6, F-7 and F-8 list linkages classified according to categories 1 through 5 respectively. In the first four tables, the numbers in the columns under "FREQUENCY" refer to the number of references containing the link at the value shown.

Table F-4

CATEGORY 1 LINKS

		FREQUENCY			
LINK	COUPLING POTENTIAL	HIGHLY RELEVANT AND THOROUGH	MEDIAN	MARGINAL	MISSED OPPORTUNITIES
1152	1	10	9	10	1
1461	1	5	8	8	2
1462	1	10	7	7	1
1852	1	6	4	9	1
1861	1	3	3	3	2
1862	1	4	4	4	1
1952	1	7	3	5	1
2433	1	2	1	2	1
3435	1	2	1	2	2

Table F-5

CATEGORY 2 LINKS

LINK	COUPLING POTENTIAL	FREQUENCY: HIGHLY RELEVANT AND THOROUGH	FREQUENCY: MEDIAN	FREQUENCY: MARGINAL	FREQUENCY: MISSED OPPORTUNITIES
1261	.5	1	0	1	1
1262	.5	1	0	1	1
1352	1	1	1	3	1
2233	.5	1	0	0	1
2243	.5	1	0	0	1
2425	1	1	1	1	2
2443	.5	1	1	2	1
2833	1	1	0	1	1
2843	1	1	0	1	1
3434	.5	1	1	2	3
3724	.5	1	1	1	3
3725	.25	1	2	2	2
3726	.5	1	0	3	2
3727	.5	1	0	3	2

Table F-6

CATEGORY 3 LINKS

LINK	COUPLING POTENTIAL	FREQUENCY: HIGHLY RELEVANT AND THROUGH	FREQUENCY: MEDIAN	FREQUENCY: MARGINAL	FREQUENCY: MISSED OPPORTUNITIES
2421	1	0	2	3	2
2435	1	0	1	1	1
2445	.5	0	1	2	1
2721	1	0	1	3	2
2725	1	0	1	1	2
2845	1	0	1	0	1
3436	.25	0	1	2	2
3437	.25	0	1	2	2
3734	.5	0	2	1	3
3735	.25	0	2	3	2

Table F-7

CATEGORY 4 LINKS

	FREQUENCY			
LINK	HIGHLY RELEVANT AND THOROUGH	MEDIAN	MARGINAL	MISSED OPPORTUNITIES
1252	0	0	2	1
2426	0	0	1	2
2432	0	0	4	1
2435	0	0	3	2
2726	0	0	1	2
2832	0	0	1	1
2834	0	0	1	1
2835	0	0	0	1
2842	0	0	1	1
3523	0	0	1	1
3524	0	0	1	1
3526	0	0	1	1
3527	0	0	1	1
3623	0	0	1	1
3624	0	0	1	1
3626	0	0	1	1
3627	0	0	1	1
3633	0	0	1	1
3634	0	0	1	1

Table F-8

CATEGORY 5 LINKS

2231	2436	3521	3636	3737
2232	2442	3522	3637	3031
2234	2444	3525	3721	3032
2235	2831	3621	3722	3033
2236	2836	3622	3723	3034
2242	2844	3625	3731	3035
2244	3431	3631	3732	3036
2245	3432	3632	3733	3037
2431	3433	3635	3736	

From these tables it is apparent that the most concentration (Category 1) is at the One-on-One level of combat and that the value of that concentration is fairly evenly distributed among marginal, median and thorough coverage. Table F-9 shows the breakout of coverage by categories 1-5 and level of combat.

Table F-9

COVERAGE BY CATEGORY AND LEVEL OF COMBAT

LEVEL	POTENTIAL	CATEGORY 1	2	3	4	5
One-on-One	11	7*	3	0	1	0
Small Unit	36	1	6	6	7	16
C/A Force	49	1	5	4	10	29
	96	9	14	10	18	45

*Figures reflect number of links.

The five most frequently covered links with marginal or better information are shown in Table F-10.

Table F-10

FIVE MOST FREQUENT LINKS

LINK	COVERED IN NUMBER OF REFERENCES: MARGINAL OR BETTER	THOROUGH
1152	29	10
1461	21	5
1462	24	10
1852	19	6
1952	15	7

Only five of the 96 possible direct linkages are thoroughly covered in five or more references. It must be pointed out, however, that instances of category 1 (Table F-4) represent different kinds of information that are thoroughly covered. The quality of the coverage will be further investigated in Section F.2.4.

Predominant movement characteristics in Category 1 are 1 (Acceleration), 4 (cross country speed), 8 (traction) and 9 (turning radius). There is an apparently poor coverage in the literature of gradability, braking, movement range, RAM-D, road speed and water speed with regard to their influences on mission performance (although all water speed linkages are not potentially highly coupled).

Category 2 and 3 linkages appear to need more attention, particularly where the degree of coupling is potentially high. The linkages for which this is so are shown in Table F-11.

Table F-11

CATEGORY 2 AND 3 LINKAGES NEEDING MORE CONCENTRATION

CATEGORY 2	CATEGORY 3
1352	2421
2425	2435
2833	2845
2843	

Among these linkages, the impact of cross country speed and traction on small unit mission performance is particularly neglected. There was one link representing impact of cross country speed on small unit mission that just made category 1 (Table F-4) with two references.

Category 4 (Table F-7) represents an almost total neglect of links with the highest potential for impact on combat mission performance (highest coupling). Among these is the impact of gradability on survival at the one-on-one level (one link), the impact of cross country speed, road speed, and traction on small unit mission performance (as with categories 2 and 3), and the impact of movement range and RAM-D on combined arms force mission performance.

In order to quantify further the degree of coverage of the impact of movement characteristics on tactical mission performance, the most frequently and thoroughly covered links (Category 1) were further examined for the kind of information which was represented in the literature.

F.2.4 Classification By Kind of Information

Table F-12 shows the breakout by kind of information for Category 1 links that were valued at median or better coverage.

Table F-12

CATEGORY 1 LINKS BY KIND OF INFORMATION FOR THOSE REFERENCES HAVING THOROUGH OR MEDIAN COVERAGE

(Note: One Link in One Reference May Cover More Than One Kind of Information)

	KIND OF INFORMATION															
	1		2		3		4.1		4.2		4.3		5		6	
LINK	3*	2*	3	2	3	2	3	2	3	2	3	2	3	2	3	2
1152	1	1	6	5	3	2	3	2	1	3	2	1	6			
1461		2	4	4	2	1	2	2	2	2	1	1	2			
1462	1	3	6	3	4	1	1	2	2	2	2	1	3			
1852			3	2	1		1	1			1	2	3	1		
1861			1	2	2		2	1	1				1	1		
1862			2	2	3		2	1	1			1	2	1		
1952			2	3	2		3				1	1	3			
2433			1	1	1				2	1	1					
3435			1						1	1	2					

*Value Level: 3 = Highly Relevant and Thorough Coverage
2 = Median Coverage

Observation: dominant coverage is 1152, 1461, 1462 and represents a concentration on the trade-off of mobility/agility for survivability. The kinds of information are restated in Table F-13.

Table F-13

KIND OF INFORMATION

CODE	KIND OF INFORMATION
1	Performance Measures
2	Effectiveness Measures
3	Performance Data
4.1	Testing
4.2	Modeling
4.3	Analytic
5	Trade-Offs
6	Gaps

In the main, literature germane to the value of tactical mobility has not analyzed its own gaps* (6). Also performance measures are slighted in terms of their use as a tool to relate movement characteristics to mission performance. There are many vehicular performance measures in the literature at the technical level; but little attempt to relate them to combat mission outcome. Links 1152, 1461 and 1462 clearly represent the best coverage by both value and kind of information. If this is so, then the concentration of mobility literature that fits the taxonomy is on about 3% of all 96 direct links. However, one-third or 32 direct links have potentially high coupling to mission performance. The above three links are included in the 32. On the basis of best payoff the mobility literature appears concentrated on less than 10% of those portions of the taxonomy where the potential influence is high.

F.2.5 Apparent Gaps According to Frequency and Value of Coverage

By reviewing the five categories of links found or not found in the literature together with the potential coupling of the links, there appears to be a basic neglect of relating movement characteristics to combat outcome above the One-on-One level. The impact of gradability on survival at the One-on-One level, cross country speed

*However, much of the literature which did not form links did address gaps.

and traction on small unit mission performance and movement range and RAM-D on combined arms force performance is neglected.

F.2.6 Apparent Gaps by Kind of Information

The tactical mobility literature has not analyzed its own gaps in relating movement characteristics to mission performance. There is poor coverage of the influence of performance characteristics on mission outcome. Except for the three links 1152, 1461, and 1462 the coverage at the current tactical mobility literature by information spectrum ranges from spotty to neglect.

F.3 QUALITATIVE RESULTS OF TAXONOMY APPLICATION

In subsection F.2 above, the taxonomy application isolated areas of almost intense concentration (3 links) and areas of neglect. This subsection will focus on what the literature had to say about that portion of the taxonomy where the effort appears concentrated and an analysis of why it fell short in the neglected areas.

F.3.1 Analysis of References Having High Valued Links

There were nine links which were high valued and which were found in two or more references (Category 1, Table F-4). These references were reviewed to discover what observations could be made regarding those links.

OBSERVATIONS:

- The influence of mobility and agility of the tank on the increase of survival probability can be characterized by the standard deviation of the apparent acceleration (Reference 2).
- Survivability increases with horsepower per ton to about 60 to 80 hp/ton (References 13, 16).
- Apparent target motion (as opposed to absolute target motion) significantly influences gunner performance (Reference 25).

- A 60 degree slalom course as a mode of travel could reduce hit probability from .8 to .2 if apparent motion can be altered rapidly as a function of time (Reference 27).
- Vehicles such as the Twister and the Scout are hard to track (by M60 A2 gunners) when they make abrupt turns. The greatest difficulty occurred when either vehicle doubled back in its own dust (Reference 27).
- It may be assumed that the threat remains constant during a maneuver that lasts only a short time. Thus armor protection and mobility can be studied independently of armament (Reference 47).

COMMENT:

There is some conflict in the literature regarding the trade-off of armor protection for agility. Some analyses are showing an increase in survivability, others a decrease. This needs to be resolved and perhaps the key is how much cost-effective power increase can accompany the increase in armor protection.

- The dominance of the XM-1 tank was found to be due primarily due to its armor protection and its ability to shoot accurately on the move (Reference 65).
- A slowly moving target is harder to hit than is implied by many of the commonly used hit probability models (Reference 13).
- Tanks running a straight line course at maximum speed have a better chance of survival than for cases of deliberate slowing down and accelerating. The hit probability in the latter case is smaller but the increased running time allows the enemy to fire more shots (Reference 13).

- Optimal evasive maneuvers are safer than straight line runs when appreciable gunner lag times exist (Reference 47).

- Steady state targets could suffer a hit probability of .8 in modern combat (Reference 27).

- A light tank with little armor protection improves slightly if its mobility is increased. However a greater gain in survival is achieved by increasing armor protection even at the expense of reduced mobility (Reference 13).

- The TOW mount had a slight tendency to overswing when tracking a rapidly moving target traveling at right angles to the launch tube's axis (Reference 27).

- As tank speed increases the offensive vehicle is intervisible for shorter periods of time. The probability of becoming engaged decreases. There is a reduction in defensed produced casualties (Reference 41).

- Weapons performance measures against targets moving at uniform velocity may be considered inflated over those in an operational environment (Reference 4).

- A gunner elevation error is easy to make if a target vehicle turns abruptly (Reference 27).

- Tank speed effects on gunners are not sensitive to tactics employed by the attackers (Reference 41).

- The average rate of movement of large maneuver units is constrained by the capability of its surveillance and by the speed of the C^3 process. Once in motion large units are further constrained by the lowest speed vehicles in the march columns (Reference 64).

- The CARMONETTE excursions and analysis of the DBM games indicate that the M60 A3 is not able to take full advantage of its increased mobility in the defense due to its increased vulnerability relative to the XM-1 (Reference 65).
- In many cases the movement was to blocking positions and because of the short movement distances involved, both high and low mobility versions arrived in sufficient time to prepare the positions prior to contact (Reference 65).
- Most rounds fired at tactical-type targets will be fired at targets which are only partially visible (Reference 4).
- Lay error is a very major (if not dominant) source of error in shooting at a maneuvering target. Prediction can reduce the error only a limited amount. The only truely effective solution is to reduce the lay error or else be prepared to shoot in any more rounds (Reference 14).
- The study (HERO) showed that the side with the more mobile tanks tended to win, but was not able to show that the tanks won because they were mobile (Reference 35).
- An advancing tank can reduce P(H) to .01 by performing a fast turn behind a smoke screen out of the way of an on-coming missile (Reference 36).

The above observations are generally related to the issue of the trade-off of mobility/agility with increased armor protection for increased survivability. Were it not for this issue much of the tactical mobility literature would disappear. There are many areas that have remained neglected in the value of tactical mobility.

F.3.3 Analysis of Areas Lacking Coverage

In many cases the classification and evaluation process did not give credit for influence of movement characteristics on mission performance above the One-on-One level. Although there was some effort to simulate or analyze more than One-on-One level combat, there was no mechanism to measure mission performance at small unit and force levels. As an example, the influence of movement characteristics on seizing or denying the seizure of an objective was seldom measured. (A notable exception to this trend was the XM-1 COEA; Reference 65).

F.3.4 Minimum Essential Requirements to Provide Missing Coverage

This section has concerned itself mainly with the direct link coverage by the literature. The indirect links expand the possible areas to be measured from 96 to 532. There are two approaches to use in applying the taxonomy. One would be hierarchial in nature and would involve an approach close to that taken in the XM-1 COEA (Reference 65). In an ideal hierarchy of models one could vary movement characteristics and measure the impact all the way to force level. This can invoke the curse of dimensionality. A two level factorial experiment of varying the movement characteristics would involve 256 runs (with each run possibly requiring a statistically comfortable number of replications) for each scenario, force level, environmental situation. The output variation would be measured along 532 links. An alternate approach is to experiment at each of the three levels of combat with the direct links only. The indirect links carry results of mission outcome to a next higher level without being mindful of how those results occurred. Implicitly this could be covered by parametric inputs. This thesis is still a dimensional curse in that each

experiment requires varied movement characteristic inputs at each level in addition to three parametric variations at level 2 and seven parametric variations at level 3. It is doubtful that there exists a model hierarchy that is sufficiently sensitive to the required input variations for either of the above approaches. Another approach is to concentrate on the potentially highly coupled links which have been neglected by the literature and investigate these analytically and with the results of current models and field tests. An application of the taxonomy to assist this process is discussed in subsection F.5 below. As a start point, concentration on Category 4 links (Table F-7) requires analysis of one One-on-One link, seven small unit links and 10 combined Arms Force links. Notably there are no more than two movement characteristics involved at each level. This seems a high payoff next step in gaining insights into movement characteristics influences.

F.3.5 Weighted Coverage versus Payoff Potential

When the potential coupling-to-mission performance is normalized and apportioned among the levels, the first column in Table F-14 results. This represents a relative index of payoff potential for movement characteristics at each level. A weighted index for coverage is also developed to form the second column for each level in Table F-14. This coverage index results from weighting highly relevant and thorough coverage at a value of 1; median coverage at .5, marginal coverage at .25, and missed opportunities at zero. The coverage thus derived for each link is then aggregated by echelon and movement characteristic* (first two digits). The second column shows the results of the latter process.

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* Note: Coverage of indirect links (between levels) by the literature was not credited. While it was potentially present in the literature, its value was predominantly a missed opportunity.

Table F-14

WEIGHTED COVERAGE VERSUS PAY-OFF POTENTIAL

MOVEMENT CHARACTERISTIC	ONE-ON-ONE		SMALL UNIT		COMBINED ARMS FORCE	
	INDEX OF PAYOFF POT'L	INDEX OF W'TD COV'G	INDEX OF PAYOFF POT'L	INDEX OF W'TD COV'G	INDEX OF PAYOFF COV'G	INDEX OF W'TD COV'G
Traction	18	1	3	6		30
Cross Country Speed	22	1	8	6	6	30
Gradability	2	1	2	3		15
Road Speed			2	1	9	5
RAM-D					2	4
Acceleration	14	0.5		1		4
Braking	2	0.5		1		4
Turning Radius	8	0.5		1		4
Movement Range					1	2
Water Speed						0.5
Total	67	4.5	15	19	18	100

Note that where the potential payoff is relatively great, the coverage is relatively small or nonexistent. Likewise where the potential payoff is relatively small, the coverage is generally large. This does not mean that the lower level research was in vain or not needed. It obviously must be done in order to embark on work at the higher levels of combat. However it is another indication of work that needs to be done.